Arlington Conservation Commission

Date: Thursday, January 5, 2023
Time: 7:00 PM
Location: Conducted by Remote Participation

Pursuant to State Legislation suspending certain provisions of the Open Meeting Law, G. L. c. 30A, § 20 relating to the COVID-19 emergency, the January 5, 2023, public meeting of the Arlington Conservation Commission shall be physically closed to the public to avoid group congregation. The meeting shall instead be held virtually using Zoom. Please register in advance for this meeting. Reference materials, instructions, and access information for this specific meeting will be available 48 hours prior to the meeting on the Commission's agenda and minutes page.

Agenda

1. Administrative
   a. Minutes
   b. Correspondence Received
2. Updates
   a. Water Bodies Working Group
   b. Park & Recreation Commission Liaison
   c. Tree Committee Liaison
3. Discussion
   a. CPA Application Updates
   b. Request for Certificate of Compliance: 1167R Massachusetts Avenue
   c. Artificial Turf Discussion
   The Conservation Commission will hear evidence for and against a prohibition of artificial turf in wetland jurisdictional areas.
4. Hearings

   Notice of Intent: 40-42 Forest Street

   Notice of Intent: 40-42 Forest Street
   Documents: 40-42 Forest Street Notice of Intent Application Package

   This public hearing will consider a Notice of Intent for work at 40-42 Forest Street. Proposed activities include partial demolition of the existing two-family house and the removal of various site features within the Riverfront Area to Mill Brook, as well as Buffer Zone, Adjacent Upland Resource Area, and

Land Subject to Flooding (Zone AE).

Town of Arlington, Massachusetts

Request for Certificate of Compliance: 1167R Massachusetts Avenue

Summary:
Request for Certificate of Compliance: 1167R Massachusetts Avenue

ATTACHMENTS:

	Type	File Name	Description
🗋	Reference Material	1165R_Mass_Ave_COC_Request_Package.pdf	1165R Mass Ave COC Request Package

Massachusetts Department of Environmental Protection
Bureau of Resource Protection - Wetlands
WPA Form 8A – Request for Certificate of Compliance
Massachusetts Wetlands Protection Act M.G.L. c. 131, §40

DEP File Number:
091-0314
Provided by DEP

A. Project Information

Important: When filling out forms on the computer, use only the tab key to move your cursor - do not use the return key.

1. This request is being made by:

Arlington Center Garage and Service Corp.
Name
438 Massachusetts Avenue
Mailing Address
Arlington | MA | 02474
City/Town | State | Zip Code
617-957-1855
Phone Number

2. This request is in reference to work regulated by a final Order of Conditions issued to:

Arlington Center Garage and Service Corp.
Applicant
11/20/2019 | 091-0314
Dated | DEP File Number

Upon completion of the work authorized in an Order of Conditions, the property owner must request a Certificate of Compliance from the issuing authority stating that the work or portion of the work has been satisfactorily completed.

3. The project site is located at:

1167-R Massachusetts Avenue | Arlington
Street Address | City/Town
 | 057.0 0002 0010.B
Assessors Map/Plat Number | Parcel/Lot Number

4. The final Order of Conditions was recorded at the Registry of Deeds for:

same
Property Owner (if different)
Middlesex | 73747 | 107
County | Book | Page

Certificate (if registered land)

5. This request is for certification that (check one):

☒ the work regulated by the above-referenced Order of Conditions has been satisfactorily completed.

☐ the following portions of the work regulated by the above-referenced Order of Conditions have been satisfactorily completed (use additional paper if necessary).

☐ the above-referenced Order of Conditions has lapsed and is therefore no longer valid, and the work regulated by it was never started.

A. Project Information (cont.)

6. Did the Order of Conditions for this project, or the portion of the project subject to this request, contain an approval of any plans stamped by a registered professional engineer, architect, landscape architect, or land surveyor?

   ☐ Yes — If yes, attach a written statement by such a professional certifying substantial compliance with the plans and describing what deviation, if any, exists from the plans approved in the Order.

   ☒ No

B. Submittal Requirements

Requests for Certificates of Compliance should be directed to the issuing authority that issued the final Order of Conditions (OOC). If the project received an OOC from the Conservation Commission, submit this request to that Commission. If the project was issued a Superseding Order of Conditions or was the subject of an Adjudicatory Hearing Final Decision, submit this request to the appropriate DEP Regional Office (see http://www.mass.gov/eea/agencies/massdep/about/contacts/find-the-massdep-regional-office-for-your-city-or-town.html).

EcoTec, Inc.

ENVIRONMENTAL CONSULTING SERVICES
102 Grove Street
Worcester, MA 01605-2629
508-752-9666 – Fax: 508-752-9494

September 9, 2022

Arlington Conservation Commission
730 Massachusetts Ave
Arlington, MA 02476 via USPS and email: concomm@town.arlington.ma.us

Re: 1167-R Massachusetts Avenue
OOC File # 091-0314

Subject: Monitoring of Proposed Plantings and Request for Certificate of Compliance

Dear Commission Members:

On behalf of the owner/ applicant, in accordance with special condition #42 of the above-referenced Order of Conditions, EcoTec provides the following monitoring report to the Commission. This report is the third of three required annual monitoring events.

On August 18, 2022, Paul J. McManus, PWS of EcoTec inspected the site for the purpose of evaluating site conditions in general and the restoration planting area in particular.

General Conditions: All of the proposed site work has been completed. This includes the deck structure, the reconstruction of the protective box around the water pipe where it spans Mill Brook, and the mitigation plantings. The work area exhibited no evidence of erosion, and all construction debris has been cleaned up and properly disposed. The erosion control barriers have been removed. The small stone dissipater pads at the terminus of each downspout pipe remain in place and no erosion was observed below the downspouts. Representative photographs of the area are attached.

Plantings: On the date of the site inspection, a multiple planted shrubs were observed, however the area was dominated by herbaceous cover, including the planted ferns and other vegetation which has colonized the area, including substantial cover by goldenrods (*Solidago* spp.). Due to the dense herbaceous cover and inability to access the area because of nearby construction across the brook, a precise shrub count is not provided. Nevertheless, it is my opinion that the proposed planting program has achieved the goal of enhancing natural cover to the area, to the extent feasible given the dense shading by adjacent buildings and a canopy dominated by Norway maple (*Acer platanoides*). Comparison of the 2019 pre-construction view of the planting area (photo below) with current conditions (appended photos) illustrates the basis for this conclusion. Continued expansion of the existing plant community is expected.

Pre-Construction View of Planting Area 10/11/2019

Summary: It is my opinion that the goal of the proposed planting plan has been achieved.

Request for Certificate of Compliance: Special Condition #31 states that a Request for Certificate of Compliance shall be accompanied by a plan stamped by a professional engineer, land surveyor or landscape architect, however no such plan was provided as part of the Notice of Intent, due to the small size of the proposed deck, and lack of grade changes. The proposed deck was constructed as approved, and the planting plan implemented as described herein. The success of the planting plan is the primary condition for measuring compliance in my opinion, and therefore on behalf of the applicant, I request that the Commission issue a Certificate of Compliance. A completed WPA Form 8A is attached.

I hope that this information is helpful to the Commission. Please contact me with any questions.

Sincerely,

Paul J. McManus

Paul J. McManus, LSP, PWS
President

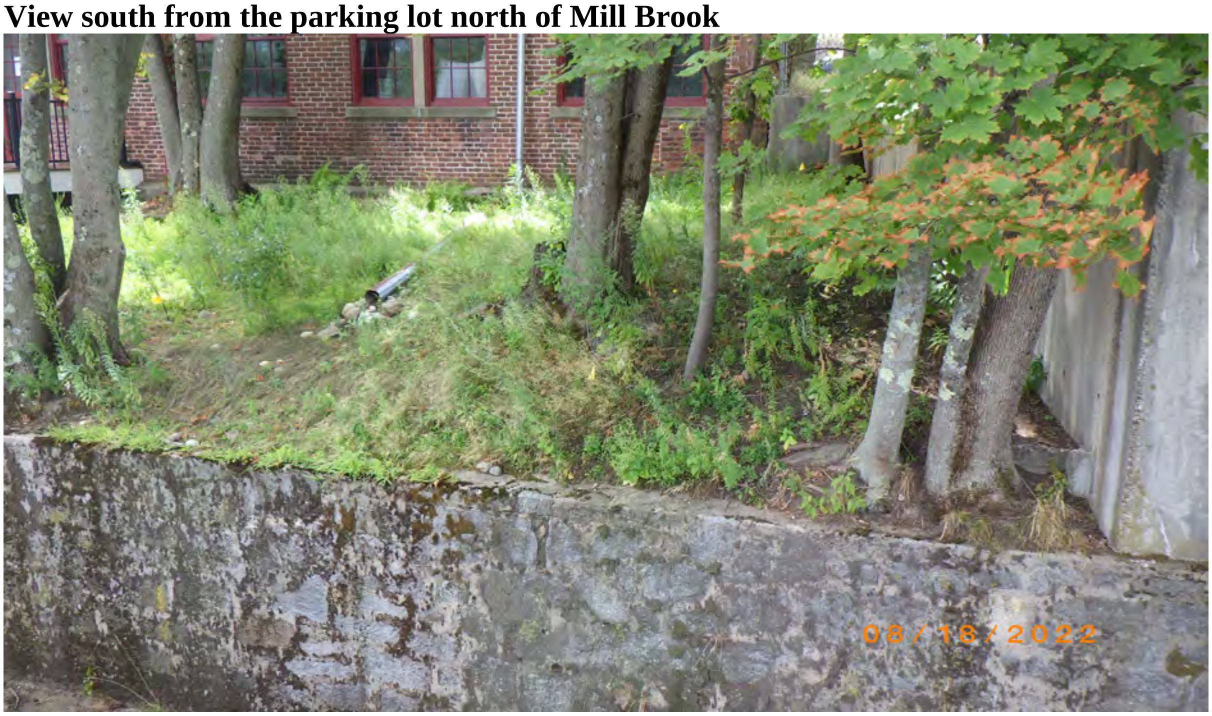
c: Applicant: Arlington Center Garage and Service Corp.

PJM\W\A\\M\K\ Arlington MassAve.1167R Monitoring 2022.08.18 inspection.doc

Enc: Site photographs 8/18/2022
WPA Form 8A – Request for Certificate of Compliance

View from the north over Mill Brook toward completed deck

View south from the parking lot north of Mill Brook



View southeast from the abutting parking lot to the west

View northeast from abutting parking lot to the west

MEMORANDUM

Date: December 9, 2022
To: Arlington Conservation Commission, c/o David Morgan
From: Ryan Clapp
Re: Certificate of Compliance - DEP #091-0314: #1167R Massachusetts Avenue

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A Request for a Certificate of Compliance for DEP #091-0314 was received by the Arlington Conservation Commission on September 14, 2022. The details of the Order of Conditions are as follows:

Address:	1167R Massachusetts Avenue
Applicant:	Arlington Center Garage and Service Corp.
Date of Issuance:	November 20, 2019
Recording Information:	Middlesex; Book 73747, Page 107
Approved Work:	Installation of exterior deck, construction of fence, repair of wooden enclosure

On November 3, 2022, with the Applicants, I visited the site at #44 Hopkins Road to confirm that the project had been completed in accordance with the site plans, narrative, and Order of Conditions. Please see the attached photographs taken as exhibits.

Based on my observations onsite, I recommend the Arlington Conservation Commission issue a Certificate of Compliance for DEP #091-0314: #1167R Massachusetts Avenue.


JM EAGLE
4" 12454 PVC SEWER PIPE ASTM D2729
JM90 ME


HYUNDAI

Town of Arlington, Massachusetts

Artificial Turf Discussion

Summary:
Artificial Turf Discussion
The Conservation Commission will hear evidence for and against a prohibition of artificial turf in wetland jurisdictional areas.

ATTACHMENTS:

	Type	File Name	Description
🗋	Reference Material	Evidence_Submitted_by_Conservation_Commission.pdf	Evidence Submitted by Conservation Commission
🗋	Reference Material	Evidence_Submitted_by_Park_and_Recreation_Commission.pdf	Evidence Submitted by Park and Recreation Commission

Intro Statement

The purpose of Arlington's Wetlands Protection Bylaw is "to protect the wetlands, water resources, and adjoining land areas in Arlington by controlling activities deemed by the Conservation Commission likely to have a significant or cumulative effect upon resource area values, including but not limited to, the following: ground water supply, flood control, prevention of pollution, wildlife protection, plant or wildlife habitat, aquatic species and their habitats, and the natural character or recreational values of the wetland resources (collectively, the "resource area values protected by this Bylaw").

This purpose is achieved by requiring anyone wishing to remove, fill, dredge, discharge into, build upon, degrade or otherwise alter any marsh, freshwater wetland, vernal pool, wet meadow, bog, swamp, river, stream, creek, pond, reservoir, or lake, or any bank to said waters, or any land under said waters, or any land bordering thereon or riverfront area as hereinafter defined, or any land subject to flooding or inundation (collectively, "the resource areas protected by this Bylaw" or "resource areas") to file an application with the Conservation Commission to review and approve, approve with conditions, or deny the proposed work.

Over the years, the Commission has granted permits to and monitored projects that include artificial turf playing fields, such as at the Arlington High School and Arlington Catholic High School. During those proceedings, and after, the Commission has become aware of the growing body of science that looks at whether all or some types of artificial turf fields, or their components, have a significant or cumulative effect on resource areas and resource area values.

The purpose of this evening's meeting is to review the Commission's experience with, and the scientific papers and studies about, artificial turf fields.

This is in the context of the Commission revising its Wetland Regulations.

Statement of Susan Chapnick as a member of the ACC:

It is my opinion that the current weight-of-evidence points to adverse effects on wetland resource areas and resource area values from Artificial Turf Fields and negative climate resilience impacts. Arlington Bylaw Article 8 Section 4 states that in order to receive a permit, it must be "proven by a preponderance of the evidence that 1) there is no practicable alternative to the proposed work or project with less adverse effects and that 2) such activity, including proposed mitigation measures, will have no significant adverse impact on the resource areas or resource area values protected by the Bylaw." In addition, the Arlington Wetland Regulations (Section 31) currently require compliance with Climate Change Resilience standards to protect resource areas that may be directly impacted by "extreme weather events expected to be more prevalent or more intense due to climate change, in surface runoff of pollutants, and in wildlife habitat."

It is my opinion that the Conservation Commission prohibit Artificial Turf Fields in jurisdictional Wetland Resource areas due to the significant adverse impacts on the resource areas and resource area values and adverse impacts to climate change resilience. The evaluation of practicable alternatives, such as organically managed natural turf fields, may be further discussed.

My reading of several scientific studies (cited below) discussed the following Adverse impacts:

1) Chemical Pollution: Toxic chemicals in some of the parts that make up an artificial turf field are harmful to wetland resource areas because they can migrate through leaching, airborne dust, volatilization, and physical migration of infill particles. Known toxic chemicals including zinc, lead, polyaromatic hydrocarbons (PAHs), phthalates, and volatile organic compounds (VOCs), have been documented (1, 2, 5, 6). Synthetic grass fibers are made of polyethylene or polypropylene. Direct toxicity to aquatic organisms has been documented from Artificial Turf Field surface runoff during rainstorms based on whole effluent toxicity (changes to runoff pH and hardness, as well as pollution from metals, semi/volatiles, and other contaminants), especially Zinc toxicity (3). Additionally, PFAS, the "forever" chemical, is found mainly in the grass blades and carpet backing material. PFAS environmental impacts from artificial turf are under-studied, but part-per-trillion (ppt) levels have been shown to have adverse effects (6) and PFAS has been documented to leach from Artificial Turf Fields (8). EPA is expecting to publish aquatic life criteria for PFAS in 2023 (9).
2) Heat effects: The plastics in Artificial turf fields exacerbate heat stress in already stressed urban resource areas of town. Temperatures of over 150 degrees F have been routinely recorded on Artificial Turf Fields during June and summer months, compared to natural grass fields with temperatures of < 90 degrees F (5). The additional heat energy shed by an artificial turf field on a hot day is estimated at 10 to 20 gigawatts (10). Cooling of artificial turf fields for use by spraying water exacerbates chemical, plastic, and particulate pollution. Increased heat effects due to climate change will add 13 to 23 days of > 90 degrees F from the current 8 days per year (Table 26, reference 7).
3) Plastic pollution: synthetic particles migrate into resource areas, resulting in plastic and microplastic pollution.
4) Particulate pollution: Crumb rubber infill routinely migrates from older fields into the surrounding resource areas, as directly seen next to Mill Brook at the Arlington Catholic Artificial Turf Field (reference Arlington Conservation Commission Letter of March 26, 2021 and subsequent Land Steward observations and pictures through December 1, 2022)
5) Climate Change resilience impacts: heat stress negatively impacts wildlife habitat values, increased pollutant loads from increased surface runoff and infill particulate migration, loss of carbon sequestration as a climate resilience strategy, limited useful lifespan (8-10 years) generates additional, recurrent installation impacts on resource areas.
6) Adverse impacts on wildlife habitat and resource area values that are harmed with an Artificial Turf field include: toxicity to aquatic life, loss of natural soil and natural grass habitat for insects and other invertebrates (especially burrowing organisms), limited foraging and prey availability for birds and small mammals, loss of pollinator use, disrupted habitat connectivity, and impacts to species composition and the water cycle owing to extreme heat.

Adverse Impacts References:

1) EPA, July 2019: Tire Crumb Rubber Characterization
https://www.epa.gov/chemical-research/july-2019-report-tire-crumb-rubber-characterization-0
2) R. Massey, L. Pollard, & H. Harari, Journal of Environmental & Occupational Health Policy, February 23, 2020 (Vol 30, Issue 1): Artificial Turf Infill: A comparative Assessment of Chemical Contents
https://journals.sagepub.com/doi/full/10.1177/1048291120906206
3) CTDEP, July 2010: Artificial Turf Study: Leachate and Stormwater Characteristics
https://portal.ct.gov/-/media/DEEP/artificialturf/DEPArtificialTurfReportpdf.pdf
4) TURI, September 2020: Athletic Playing Fields & Artificial Turf: Considerations for Municipalities and Institutions
https://www.turi.org/content/download/13271/203906/file/Factsheet.Artificial_Turf.September2020.pdf.pdf
5) TURI, April 2019 (updated): Athletic Playing Fields – Choosing Safer Options for Health and the Environment
https://www.turi.org/content/download/11980/188623/file/TURI+Report+2018-002+June+2019.+Athletic+Playing+Fields.pdf
6) TURI, February 2020: Per- and Poly-fluoroalkyl Substances (PFAS) in Artificial Turf Carpet
https://www.turi.org/content/download/12963/201149/file/TURI+fact+sheet+-+PFAS+in+artificial+turf.pdf
7) Town of Arlington Hazard Mitigation Plan – 2020 update
https://www.arlingtonma.gov/home/showpublisheddocument/51627/637268071185670000
8) York Analytical Data for PFAS from swale runoff of Amity High School Artificial Turf Field in Woodbridge, CT
https://subscriber.politicopro.com/eenews/f/eenews/?id=00000181-b526-d010-a3cb-b5aed1070000
9) PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024
https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf
10) Heat Energy Source: https://doi.org/10.1089/scc.2021.0038

Precedent in other Municipalities in MA

Several municipalities currently have banned or have a moratorium on permitting Artificial Turf fields including:

Boston – banned in 2022 due to PFAS: https://www.theguardian.com/environment/2022/sep/30/boston-bans-artificial-turf-toxic-forever-chemicals-pfas

Concord – 3-year moratorium (2016); town meeting requested another 5 year moratorium as of May 2022: https://concordma.gov/DocumentCenter/View/35180/Article-16-Moratorium-on-Installation-of-Synthetic-Turf-on-Town-Land---Citizen-Petition

Malden – residents advocating for natural grass field (2022): https://advocatenews.net/malden/news/malden-hopeful-as-boston-bans-toxic-turf/

Nantucket – 1 year moratorium (2022): https://www.ack.net/stories/nantucket-public-schools-put-artificial-turf-plans-on-hold-for-at-least-a-year,27767

Sharon – 3-year moratorium (2020): https://ecode360.com/37379890

Wayland – 3-year moratorium (2021) and evidence of crumb rubber migration into nearby waterways after storm (2021): https://ecode360.com/38888159 and https://patch.com/massachusetts/wayland/big-mess-after-storm-floods-wayland-hs-crumb-rubber-field

Practicable Alternative

Organically managed natural turf field employing aeration & mowing techniques and/or over similar stormwater infiltration systems used below artificial turf fields allow for improved drainage, organic management reduces need for extensive nutrients and harmful chemical treatments, allows for some habitat functions & values and is a more climate resilient alternative (sustainable, lower heat effects, less pollution runoff with organic management). References: Springfield with 67 acres of organically managed athletic fields (10), Marblehead with 20 acres of organically managed athletic fields (11), Martha's Vineyard (12); and the TURI report that includes cost comparison table for Artificial Turf vs. Organically managed Natural Turf (4).

Organic Natural Turf Management references:

11) City of Springfield, June 2019: Natural Grass Playing Field Case Study https://www.turi.org/content/download/12156/190509/file/Natural+Grass+Playing+Field+Case+Study+Springfield+MA.+June+2019.pdf
12) Marblehead, November 2020 (revised): Natural Grass Playing Field Case Study: Marblehead, MA https://www.turi.org/content/download/12705/198916/file/Natural+Grass+Playing+Field+Case+Study+Marblehead+MA+revised.Nov2020.pdf
13) Martha's Vineyard, December 2020: Natural Grass Playing Field Case Study: Martha's Vineyard, MA https://www.turi.org/content/download/13432/205432/file/Natural+Grass+Playing+Field+Case+Study+MV+MA.Dec2020.pdf

FINAL REPORT

Artificial Turf Study

Leachate and Stormwater Characteristics

Connecticut Department of Environmental Protection
July 2010

TABLE OF CONTENTS

TABLES

APPENDICES

1. PROJECT OVERVIEW

In December 2008, four Connecticut State agencies, the University of Connecticut Health Center, The Connecticut Agricultural Experiment Station, the Connecticut Department of Environmental Protection and the Connecticut Department of Public Health, agreed to jointly develop and implement a study to evaluate the health and environmental impacts associated with artificial turf fields. The overall objectives of the study were to:

1. Identify comprehensively substances, including organic compounds and elements, which derive from the crumb rubber infill used on synthetic turf fields, as well as currently available alternative infill products, through off-gassing and leaching pathways;
2. Establish the level of chemical variability for infill at individual synthetic turf fields and between different synthetic fields in Connecticut;
3. Measure levels of off-gassed compounds and airborne particulate matter in the normal breathing zone of children during a "simulated worse-case scenario" at athletic field(s) in Connecticut (inhalation risk);
4. Measure levels of leached compounds in storm water runoff collected in actual field conditions (environmental risk); and
5. Utilize collected data to make environmental and public health risk assessments regarding outdoor artificial turf fields.

The Department of Environmental Protection ("DEP") was specifically tasked with: (1) collecting stormwater runoff samples from the four artificial turf fields selected for the study; (2) analyzing the stormwater samples for levels of compounds leached from the artificial turf materials; (3) scientifically evaluating the laboratory analysis results; and (4) developing an environmental risk assessment for the artificial turf fields.

This report is not intended to be a comprehensive investigation of the environmental risks associated with artificial turf fields, but a basic assessment of water quality data collected from a limited number of fields during a three-month period. It should be understood, that the ultimate conclusions in the report are based on eight stormwater sampling events, essentially a "snapshot", of an ongoing chemical and physical process.

2. SITE SELECTION

The four artificial turf fields selected for DEP's stormwater sampling plan were the same fields sampled in the summer of 2009 by the University of Connecticut Health Center for airborne contaminants. Specific field selection criteria included: crumb rubber infill, owner permission, installation date, different manufacturers and site location. The owners of the selected four fields provided engineered drainage plans to DEP. DEP staff reviewed the drainage plans and established sampling points that only collected stormwater draining from the artificial turf field.

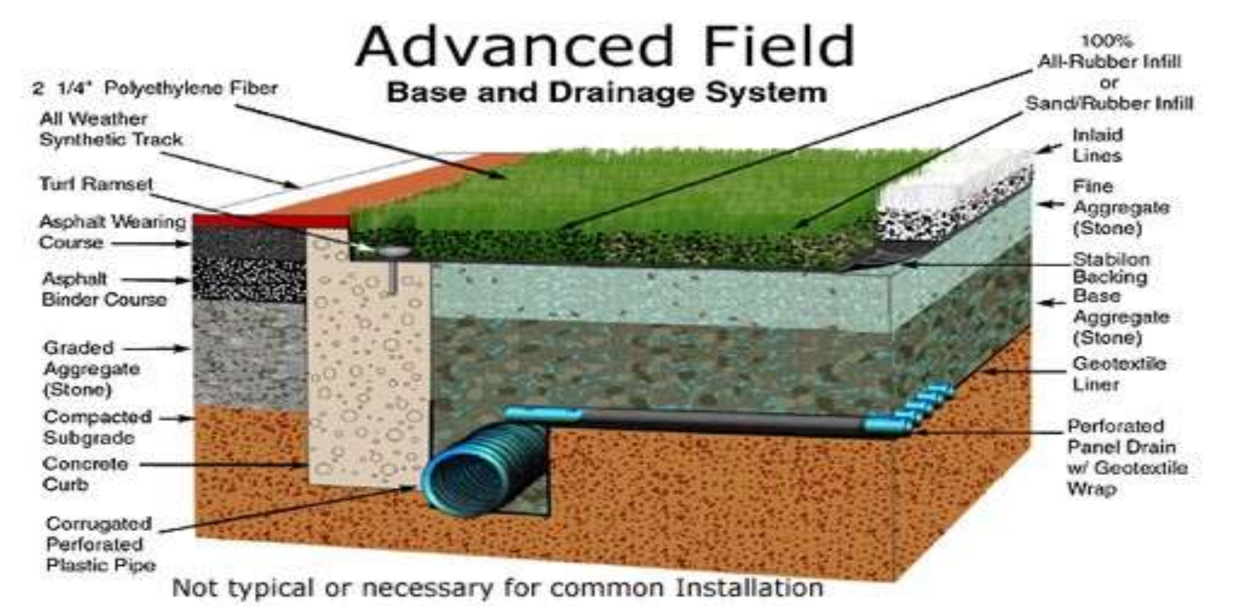
3. ARTIFICIAL TURF FIELD SYSTEMS

The artificial turf fields selected were installed by different engineering, synthetic turf and construction companies, but are similar in general design. The fields are composed of a top layer

of polyethylene or polypropylene grass fibers, with a crumb rubber (sometimes intermixed with sand) infill layer, and underlain by crushed stone/gravel with a piped drainage system (see Figures 1 and 2 below).

Figure 1.

Figure 2. (source: www.suncountrysystems.com/.../syntheticgrass.jpg)



The critical field component for this study is the infill layer, which includes crumb rubber materials produced from recycled tires. The infill layer can be composed of entirely styrene-butadiene rubber (SBR) granules, produced by ambient and/or cryogenic grinding process, or intermixed with quartz crystals (sand). The assumption for this study, and the sampling plan, is that precipitation lands on the surface of the artificial turf field, flows downward through the infill and rock/gravel layers, collects in the subsurface drain pipes and then ultimately discharges from the field. The artificial turf drainage pipes often discharge to existing subsurface drainage

systems at catch basin and/or manhole connections. The subsurface drainage pipes utilized under the fields can be solid or perforated.

4. SAMPLING PROTOCOLS

DEP staff reviewed EPA protocols and previous artificial turf leaching studies and established the following stormwater sampling plan:

1. Sampling Plan
    a. One sampling station was established at each of the four artificial turf fields;
    b. The sampling stations were located at a point where runoff was only from the artificial turf field;
    c. The size of the drainage area (in square feet) to each sampling station was calculated;
    d. Grab samples were collected and delivered to the laboratory by qualified individuals during the fall of 2009; and
    e. Samples were analyzed by an EPA certified laboratory.

2. Storm Event Criteria
    a. Samples were collected from discharges resulting from a storm event that was greater than 0.1 inch in magnitude and that occurred approximately 72 hours after any previous storm event of 0.1 inch or greater;
    b. Grab samples were collected during the first 30 minutes of a storm event discharge, or as close thereto as possible, and were completed as soon as possible;
    c. The following information was collected for the storm events monitored:
        i. The date, temperature, time of the start of the discharge, time of sampling, and magnitude (in inches) of the storm event sampled; and
        ii. The duration between the storm event sampled and the end of the previous measurable (greater than 0.1 inch rainfall) storm event.

3. Sampling Procedures
    a. Grab sample collection, chain of custody and laboratory delivery were performed in accordance with the EPA NPDES Stormwater Sampling Guidance Document (EPA 833-B-92-001, 7/92); http://www.epa.gov/npdes/pubs/owm0093.pdf
    b. Laboratory analysis of grab samples included the following:
        i. Acute Toxicity 48 hour LC50 *Daphnia pulex* & 48 hour and 96 hour LC50 *Pimephales promelas* (EPA 821-R-02-012).
        ii. EPA Method 130.1, Hardness, Total (mg/L as $CaCO_3$)
        iii. EPA Method 150.2, pH
        iv. EPA Method 200.7, (Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Thallium, Vanadium and Zinc)
        v. EPA Method 624, Volatile Organic Compounds
        vi. EPA Method 625, Semivolatile Organic Compounds (TIC's for Benzothiazole, Butylated hydroxyanisole (BHA), n-hexadecane and 4-(t-octyl) phenol.

5. FIELD SAMPLING METHODS

In September of 2009, the stormwater sampling plan was implemented at the four artificial turf fields: Field A, Field B and Field D all constructed in 2007; and Field C constructed in 2005. Stormwater samples were successfully collected from Fields A, C and D. Field B was visited during five precipitation events and no discharge from the established sampling station was observed. A total of eight stormwater samples were collected from Fields A, C and D between 9/11/09 and 12/3/09. Based on DEP staff observations, Fields B and C did not appear to regularly discharge runoff during or after precipitation events, while Fields A and D discharged during and after every precipitation event monitored. For the one sample collected from Field C, DEP staff was fortunate to experience an extremely hard (downpour) rain event that exceeded the infiltration rate of the perforated underdrain system. DEP staff reviewed the engineered drainage plans and determined that Fields B and C utilized perforated drainage pipes causing the stormwater to normally infiltrate into the soil beneath the fields. Fields A and D utilized solid drainage pipes, which discharge the stormwater to local drainage systems at the sites, similar to an impervious surface.

For each precipitation event, stormwater collected at the fields was sampled for total metals, hardness, pH, volatile organic compounds, semi-volatile organic compounds (including rubber Tentatively Identified Compounds found by The Connecticut Agricultural Experiment Station in a 2007 study), pesticides/ polychlorinated biphenyls (PCBs) and acute aquatic toxicity (48 hours for *Daphnia pulex* (Dp)and 96 hours for *Pimephales promelas*(Pp)). Stormwater samples were analyzed at the Connecticut Department of Public Health Laboratory, Environmental Chemistry Division, Inorganic Chemistry Section, 10 Clinton Street Hartford, CT 06106 for pH, Hardness and Total Metals; at Phoenix Environmental Laboratories, Inc. 587 East Middle Turnpike, Manchester, CT 06040 for volatile organic compounds, semi-volatile organic compounds, pesticides, PCBs; and at GZA GeoEnvironmental, Inc., 120 Mountain Avenue, Bloomfield, CT 06002 for acute toxicity. A summary of the tests performed on the samples collected are shown in Table A below.

Table A

Location	Date	pH	Hardness	Metals	Volatiles	Semivolatiles	Pesticides and PCBS	Aquatic Toxicity LC50		
								Dp 48 hrs	Pp 48 hrs	Pp 96 hrs
Field C	9/11/09			√	√	√	√	√		
Field A	9/27/09	√	√	√	√	√	√	√		√
Field A	10/7/09	√	√	√	√	√	√	√		√
Field A	10/18/09	√	√	√	√	√	√	√	√	
Field D	10/18/09	√	√	√	√	√	√	√	√	
Field D	10/28/09	√	√	√	√	√	√	√		√
Field D	11/20/09	√	√	√	√	√		√		√
Field D	12/3/09	√	√	√	√	√	√	√		√

6. DEP STORMWATER SAMPLING RESULTS

a) Method 624/Method 625 and Tentatively Identified Compounds(TICs):

No standard volatile or semi-volatile organic compounds were detected in any sample using the EPA 624 and 625 analytical methods. All samples were analyzed for non-standard semi-volatile organic compounds, including the following rubber compounds benzothiazole, butylated hydroxyanisole (BHA), n-hexadecane and 4-(t-octyl) phenol. The semi-volatile analysis detected the analytical peaks of twenty-two compounds, of which nine were tentatively identified (see Table B below). The concentrations of these compounds ranged from 1 ug/l to 150 ug/l. The grey columns in Table B correspond to the three stormwater samples determined to be acutely toxic. Table C details the aquatic toxicity information found for the other tentatively identified compounds listed in Table B.

b) Pesticides and PCBs (Method 608)

Pesticides

Pesticides were detected in the samples of stormwater collected on September 11, 2009 from Field C and on October 28, 2009 from Field D. DEET and heptachlor were detected at estimated concentrations of 6.9 ug/l and 0.18 ug/l, respectively. It is assumed that these substances were not derived from the artificial turf, but were a result of pesticide applications at the site.

PCBs

No PCBs were detected during the stormwater sampling events.

c) pH, Hardness and Metals:

The results from the pH, hardness and metals analysis conducted on the stormwater runoff from the fields are presented in the table below.

pH

The pH of the stormwater samples ranged from 6.6 to 8.0. The pH of stormwater in Connecticut is generally considered to be between 5.6 and 6.0. Based on this fact, the pH of the stormwater samples are more alkaline than expected. It is possible that the crushed stone used as a sub-base in the fields affected the pH of the stormwater as it drained through the field.

The pH alone does not exhibit toxic effects unless it falls below 5 or is higher than 10. However, metals are often more soluble and toxic at lower pH's. The observed neutral pH in the stormwater may have reduced the concentrations and toxicity of the metals leaching from the fields.

TABLE B

Location:			Field C	Field A	Field A	Field A	Field D	Field D	Field D	Field D
Sample #			**A**	**B**	**C**	**E**	**D**	**F**	**G**	**H**
Sample date			9/11/2009	9/27/2009	10/7/2009	10/18/2009	10/18/2009	10/28/2009	11/20/2009	12/3/2009
Parameter:	**Tentatively identified Compounds**	**CAS#**								
Heptachlor							<0.10	0.18	NT	<0.05
Retention Times (min)										
3.55			6.2							
5.04					150					
6.12			4.3							
6.63										9.5
6.81					4.1					
6.83	2- propyl-methyl pentanoic acid	22632-59-3			14	6.6				
6.85	Benzothiazole	95-16-9		1	4.9					
6.88					6.1					
7.07									5.1	
7.08	methyl 2alpha -D-xylofuranoside	32469-86-6				5.8				
7.10	2 ethyltetra hydro thiopene	1551-32-2				28				
7.13	4-methyl4-Heptanol	598-01-6				7.4				
7.15	2- butyl tetrathydrothiopene	1613-49-6				12				
7.77										10
7.96								6.6		
8.13					7.4					
8.23									7	
9.48	Benzamide, N-N- diethyl-3-methyl	134-62-3	6.9							
9.56	2(3H)- Benzo thiazolone	934-34-9			5.7					
10.28						4.1				
12.60	2-2-7 trimethyl-3-Octyne	55402-13-6					4.5			
16.88			8.4							

TABLE C

Location: Sample # Sample date			Max Concentration	Location	Acute Water Quality Criteria	Chronic Water Quality Criteria	Comments
Parameter:	**Tenatively identifeid Compounds**	**CAS#**					
Heptachlor			0.18	D	0.26	.0038	CT WQS 2002
Retention Times (min)							
3.55			6.2	A			
5.04			150	A			
6.12			4.3				
6.63			9.5	D			
6.81			4.1	A			
6.83	2- propyl-methyl pentanoic acid	22632-59-3	14	A	2812.5	312.5	Toxicity info on pentanoic acid tier 2
6.85	Benzothiazole	95-16-9	4.9	A			One data point tier 2
6.88			6.1	A			
7.07			5.1	D			
7.08	methyl 2alpha -D-xylofuranoside	32469-86-6	5.8	A			No data
7.10	2 ethyltetra hydro thiopene	1551-32-2	28	A			No data
7.13	4-methyl4-Heptanol	598-01-6	7.4	A			No data on Heptanol either
7.15	2- butyl tetrathydrothiopene	1613-49-6	12	A			No data
7.77			10	D			
7.96			6.6	D			
8.13			7.4	A			
8.23			7	D			
9.48	Benzamide, N-N- diethyl-3-methyl	134-62-3	6.9	C	89.3	9.9	DEET tier 2
9.56	2(3H)- Benzo thiazolone	934-34-9	5.7	A	47.3	8.1	Different CAS # 149304 tier 2
10.28			4.1	A			
12.60	2-2-7 trimethyl-3-Octyne	55402-13-6	4.5	D			No data
16.88			8.4				

Hardness

The hardness of the stormwater samples ranged from 8 to 59 mg/L. Hardness in the range of 0 to 60 mg/L is generally termed “soft”. Hardness can also influence the toxicity of metals; the greater the hardness, the less toxic the metals. It is not expected that the observed hardness had much effect on metal concentrations in the stormwater.

Metals

The metal parameters which had results reported above the detection limit are listed in Table C below. Silver, molybdenum, thallium and beryllium were analyzed but were below the detection limit for every sample. In Table C, the values bolded and underlined exceed Connecticut’s acute aquatic life criteria. Metal concentrations in excess of the acute aquatic life criteria for more than one hour could cause mortality to the more sensitive organisms in the receiving surface waters. The values bolded meet or exceed Connecticut’s chronic aquatic life criteria. Average metal concentrations which exceed the chronic life criteria for more than 4 continuous days are expected to impact the ability of organisms to survive, reproduce or grow. EPA recommends that neither of these criteria be exceeded more than once in three years (EPA TSD EPA/505/2-90-001). The samples highlighted in grey also exhibited acute toxicity. Since stormwater is an intermittent discharge, the acute criteria for aquatic toxicity are more applicable. A review of the data indicates that only zinc consistently violates the acute criteria.

TABLE D

Location	Sample #	Sample date	pH	Hardness	Conductivity	Cu ug/l	Zn ug/l	Ba ug/l	Fe ug/l	Al ug/l	V ug/l
Field C 2005	**A**	9/11/09	6.6	NA	18	4	**150**	4	320	**210**	40
Field A 2007	**B**	9/27/09	6.6	8	20	1.5	**130**	1.5	20	25	1.5
Field A 2007	**C**	10/7/09	7.5	29	65	1.5	10	6	50	**160**	5
Field A 2007	**E**	10/18/09	7.5	39	86	1.5	20	7	20	60	1.5
Field D 2007	**D**	10/18/09	7.6	53	130	5	**260**	**220**	170	**120**	6
Field D 2007	**F**	10/28/09	7.9	59	157	4	50	8	80	80	8
Field D 2007	**G**	11/20/09	8	56	153	4	30	7	160	**110**	9
Field D 2007	**H**	12/3/09	8	58	147	4	20	5	170	**100**	8
		acute standard	**<5.0 >10**			**14.3**	**65**	**2000**		**780**	**150**
		chronic standard	**<5.0 >10**			**4.8**	**65**	**220**	**1000**	**87**	**44**

d) Aquatic Toxicity

The toxicity tests conducted on the stormwater measured both an LC50 value (the concentration of stormwater that is lethal to 50% of the test organisms) and an NOAEL (No Observable Acute Effect Level, the concentration of stormwater where no acute toxicity is observed). Toxicity tests conducted on the samples of stormwater collected indicate that 3 out of 8 sampling events were acutely toxic. Acute toxicity is observed when there is less than 90% survival of the test organisms in the undiluted effluent. The frequency of occurrence for acute toxicity was at least one sample per field. Where both *Pimephales promelas*(Pp) and *Daphnia pulex*(Dp) toxicity tests were conducted, the fathead minnow (*Pimephales promelas*) seemed to be slightly more sensitive to the contaminants in the stormwater discharge. Due to laboratory issues, the test duration for the fish, *Pimephales promelas*, for the October 18, 2009 Field A and Field D samples was limited to only 48 hours. If the test duration was extended to 96 hours, both samples could have had an LC50 value less than the 100% reported. The results for the aquatic toxicity testing conducted are shown in Table E below.

TABLE E

Location:	Sample #	Sample date	Dp % Surv 100%	Dp LC50	Dp NOAEL	Pp % Surv in 100%	Pp LC50	Pp NOAEL
Field C 2005	*A*	9/11/2009	65.0	>100	12.5	NT	NT	NT
Field A 2007	*B*	9/27/2009	70.0	>100	50	45	93.89	50
Field A 2007	*C*	10/7/2009	100.0	>100	100	100	>100	100
Field A 2007	*E*	10/18/2009	100.0	>100	100	96	>100	100
Field D 2007	*D*	10/18/2009	70.0	>100	6.25	50	100	25
Field D 2007	*F*	10/28/2009	100.0	>100	100	95	>100	100
Field D 2007	*G*	11/20/2009	100.0	>100	100	100.0	>100	100
Field D 2007	*H*	12/3/2009	100.0	>100	100	95	>100	100

acutely toxic

7. CAES LABORATORY HEADSPACE AND LEACHING RESULTS

The CAES performed both headspace (off-gassing) and SPLP (Standard Precipitation Leaching Procedure) evaluations on seventeen samples of crumb rubber materials used as infill for artificial turf fields. These studies indicated the primary contaminants likely to be found in the stormwater coming from these sites. Organic compounds were identified by head space analysis, with results shown in Table F below. The other organic compounds detected from the crumb rubber infill, but not quantified in the analysis, included hexadecane, fluoranthene, phenanthrene and pyrene.

TABLE F. (Table 2. From CAES 2009) Concentration (ng /ml) of Volatile Compounds in Headspace Over Crumb Rubber Samples Analyzed at CAES (average of two analyses per sample)

DEP Sample ID	1-methyl naphthalene	2-methyl naphthalene	4-(t-octyl)-phenol	benzothiazole	butylated hydroxytoluene	naphthalene	butylated hydroxyanisole
A1001	0.13	0.19	0.28	3.98	n.d.	0.42	0.50
A1002	0.11	0.15	0.31	5.59	n.d.	0.31	0.61
A1003	0.03	0.07	0.19	8.67	n.d.	0.10	0.68
A1004	0.04	0.07	0.31	6.52	0.15	0.16	0.69
A1005	0.08	0.09	0.23	2.35	0.09	0.23	0.46
A1006	0.08	0.14	0.31	4.89	0.12	0.23	0.75
A1007	0.13	0.20	0.52	3.50	n.d.	0.23	0.69
A1008	0.06	0.10	0.18	1.93	n.d.	0.22	0.43
A1009	0.03	0.06	0.13	2.89	0.13	0.08	0.50
A1010	0.07	0.11	0.22	4.91	0.13	0.20	0.64
A1011	0.04	0.06	0.30	3.94	0.16	0.11	0.62
A1012	0.08	0.14	0.46	2.70	0.13	0.28	0.64
A1013	0.09	0.12	0.45	4.45	n.d.	0.30	0.65
A1014	0.10	0.15	0.49	4.25	n.d.	0.31	0.65
B1002	n.d.	n.d.	0.43	1.21	0.67	0.09	0.36
B1009	n.d.	n.d.	0.07	1.29	0.48	0.06	0.35
B1010	n.d.	n.d.	0.06	1.03	0.40	0.05	0.34

CAES also performed simulated weathering experiments on the crumb rubber samples to determine trends in organic compound emissions over time. The weathering test results show that, except for 4-(t-octyl)-phenol, all other detected volatile compounds significantly decreased in concentration after only 20 days of outdoor exposure. By the end of the eight week study, benzothiazole, butylated hydroxanisole and 4-(t-octyl)-phenol were detected at the highest concentrations. The results are shown in Table G. below.

TABLE G: (Table 9 from CAES, 2009) Concentrations (ng /ml) of Volatile Compounds in Headspace Over Crumb Rubber Samples Aged at CAES (average of two analyses per sample)

Sample ID (week)	benzothiazole	1-methyl naththalene	2-methyl naphthalene	naphthalene	4-(t-octyl)-phenol	butylated hydroxyanisole
T0	3.75	0.12	0.24	0.40	0.35	0.77
T1	1.95	0.05	0.09	0.12	0.28	0.45
T2	0.97	0.04	0.06	0.06	0.31	0.40
T3	1.56	0.04	0.07	0.08	0.31	0.44
T4	1.77	0.04	0.08	0.08	0.30	0.43
T5	1.59	0.05	0.07	0.10	0.30	0.48
T6	1.20	0.04	0.06	0.05	0.25	0.36
T7	0.99	0.04	0.06	0.04	0.24	0.33
T8	1.17	0.05	0.05	0.06	0.23	0.41

CAES also performed an SPLP test on the same seventeen samples of the crumb rubber infill material. The resulting leachate was then analyzed for metals and organic compounds. Based on communications with CAES, the leachate contained the same organic compounds that were identified in the head space analyses, however, only benzothiazole concentrations were estimated for the test. A summary of compounds detected and their concentrations are listed in Table H below. Based on these results, the predominant contaminant leaching from artificial turf fields is

zinc, followed by barium, manganese and lead. It should be noted some metals associated with tires and rubber products were not analyzed in this experiment, such as iron and vanadium.

In Table H, the values which exceed Connecticut's acute aquatic life criteria are highlighted in yellow. The summary shows that zinc is present in the leachate at concentrations about 500 times greater than the toxicity criteria. The leachate study indicates that there is a high potential for the artificial turf to leach acutely toxic levels of metals especially copper and zinc. Certain samples of crumb rubber also leached acutely toxic levels of cadmium, barium, manganese and lead.

TABLE H

	Benzothiazole	Cr	Mn	Ni	Cu	Zn	As	Cd	Ba	Pb
ug/l										
average	0.153	6.24	263.16	19.88	22.31	34170.5	3.35	1.60	313.88	11.57
80^{th}	0.209	11.28	348.45	27.48	20.41	50269.8	1.50	0.50	463.62	7.77
Max	0.268	31.47	1443.19	57.15	143.32	71535.5	27.94	17.01	502.91	69.90
Acute	21333.000	323	616	260.5	14.3	65	340	2.02	2000	30
Chronic	3200.000	42		28.9	4.8	65	150	1.35	220	1.2

8. DISCUSSION

a) Potential Contaminants

The analyses performed on the stormwater samples were focused on compounds previously documented to leach from crumb rubber material derived from recycled tires, primarily volatile organic compounds, semi-volatile organic compounds and metals. The stormwater samples were also assessed for whole effluent toxicity. Other potential parameters of concern in the stormwater were identified from the results of the CAES off-gassing and leaching laboratory studies performed on the crumb rubber material.

b) Organic compounds

The stormwater generated at the artificial turf sites did not include many readily identifiable, volatile or semi-volatile organic compounds, as evidenced by no detections using EPA Methods 625 and 624. Additional semi-volatile compound investigations were performed on the stormwater samples, resulting in nine tentatively identified compounds and thirteen unidentified chromatograph peaks. Benzothiazole, which CAES also detected in their leaching analysis, was identified in the September 27 and October 7, 2009 samples from Field A at concentrations of 1 and 4.9 ug/l, respectively. Of the compounds that were tentatively identified such as benzothiazole, pentanoic acid, and thiopenes, none of these compounds are considered particularly toxic to aquatic organisms at the estimated concentrations.

Although it is not possible to determine the potential impact of the unidentified semi-volatile compounds, it is important to note, that the six highest concentrations of the unidentified semi-volatile compounds detected (150 ug/l, 28 ug/l, 14 ug/l, 12 ug/l, 10 ug/l and 9.5 ug/l) did not correspond to the three acutely toxic samples of stormwater determined in the study.

The results from the CAES laboratory headspace, leaching and simulated weathering tests suggest that benzothiazole, 4-(t-octyl)-phenol, 1-methyl naphthalene, 2-methyl naphthalene, naphthalene, butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) are the likely semi-volatile compounds to be found in the stormwater discharge from artificial turf fields. The test results also suggest that Benzothiazole, 4-(t-octyl)-phenol and butylated hydroxytoluene (BHT) would be the most persistent SVOCs in the crumb rubber as the artificial turf fields aged.

Comparing the VOCs and SVOCs results to EPA's Maximum Contaminant Levels for drinking water (MCLs) and DEP's Remediation Standards Regulations, Section 22a-133k-1 through 22a-133k-3of the Regulations of Connecticut State Agencies (June 1996), no exceedences of groundwater standards have been identified.

Based on our results, no VOCs or SVOCs have been identified as risks to surface and groundwater resources.

c) Metals

The laboratory leaching analyses performed by CAES as part of the State of Connecticut Artificial Turf Study detected the following metals: arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), manganese (Mn), nickel (Ni), and zinc (Zn). Zinc was present in concentrations orders of magnitude greater than the other metals. CAES's leaching analyses indicated that both copper (Cu) and zinc (Zn) concentrations exceeded acute aquatic toxicity criteria for 80% of the tests, with limited (<20%) exceedences of acute criteria for cadmium (Cd), manganese (Mn) and lead (Pb).

The stormwater analysis results show that the artificial turf fields in our study leached significantly less contaminants, specifically zinc and copper, than predicted by the CAES leaching test results. The lower metal concentrations observed in the stormwater could be a result of alkaline pHs, the weathering (2-4 years since installation) of the crumb rubber infill, or the conservative approach inherent in the SPLP methodology.

The stormwater analysis results showed that zinc was the only metal to exceed the acute aquatic toxicity criteria (65 ug/l), with one exceedence at each of the three study fields. The overall mean concentration of zinc in the stormwater samples analyzed was 84 ug/l, with a maximum of 260 ug/l and a minimum of 10 ug/l. The stormwater analysis results showed that aluminum, barium, copper and zinc all exceeded chronic aquatic toxicity criteria at least once during the sampling. Since chronic toxicity criteria apply to four days of continuous discharge, these exceedences are not of significant concern for these intermittent discharges.

No metal concentrations exceeded EPA's and DEP's drinking water standards. However, the concentration of zinc in three stormwater samples did exceed the surface water protection

criteria of 123 ug/l established in the Appendix D to Sections 22a-133k-1 through 22a-133k-3 of the Regulations of Connecticut State Agencies Surface-water Protection Criteria for Substances in Ground Water (June 1996). Since the mean concentration of zinc in the stormwater samples (84 ug/l) is below the surface water protection criteria, the discharge from the artificial turf fields to groundwater is intermittent, and zinc is immobilized in soils by adsorption, absorption and precipitation, the potential for impacts to surface waters being recharged by this groundwater is minimal.

Based on our results, zinc has been identified as a potential risk to surface waters. No other metals have been identified as a risk to groundwater or surface waters.

9. ENVIRONMENTAL RISK ASSESSMENT

a) Potential Risk to Surface Waters

The only potential risk to surface waters identified in the stormwater collected from the artificial turf fields is zinc, since it was the only chemical parameter that was detected above the acute aquatic life criteria of 65 ug/l. Acute toxicity is assumed to occur when the zinc concentration in-stream exceeds 65ug/l for one hour in any three year period. In three of the eight stormwater samples analyzed, zinc concentrations were detected at 130, 150 and 260 ug/l, well above the acute aquatic life criteria. It is important to note, that the three stormwater samples with acutely toxic levels of zinc were also determined to exhibit aquatic toxicity (<90% survivorship) for both species *Pimephales promelas* and *Daphnia pulex* in the whole effluent toxicity testing.

Other than the acute aquatic toxicity criteria, there are no specific zinc standards or permit limits that are applicable to artificial turf fields. For industrial sites that discharge to surface waters, DEP has set a stormwater general permit guideline (Section 5 (c) (1) (F) (i) of the General Permit) for total zinc of 200 ug/l. This industrial stormwater total zinc guideline assumes a default 5:1 dilution factor for the receiving surface water at the 7Q10 flow. The 7Q10 is the lowest flow expected to occur for seven continuous days at a frequency of every 10 years. The 7Q10 flow is the critical low flow used when evaluating toxicity and toxic impacts (CT WQS 2002). Based on the results of our study, the stormwater discharges from artificial turf fields would not be expected to regularly exceed this zinc limit.

However, the estimated 7Q10 flows for the receiving watercourse from Fields A, C and D did not meet the 5:1 dilution factor for stormwater discharges from artificial turf football fields (57,600 square feet), assuming a one inch rain storm over one hour with direct discharge to the watercourse over an hour. It is important to note, that this a conservative approach, which assumes the watercourse receives no other stormwater runoff from its representative watershed. For the three receiving streams in the study, the highest dilution factor at the DEP estimated 7Q10 flow was equivalent to a 0.14:1 ratio. Given this dilution ratio of the receiving streams in the study, there is a potential for acute toxicity due to zinc loading.

Since zinc concentrations in stormwater from artificial turf fields may pose a risk to surface waters, especially to smaller watercourses, it is important to note that these fields are not the only sources of stormwater runoff in any given watershed. During the sampling at Fields A, C and D,

DEP staff observed stormwater runoff, generated by acres of parking lots, roadways and buildings, entering the same drainage systems that collected runoff from the artificial turf fields. Based on these observations, it appears that stormwater runoff from the artificial turf fields is combined with the runoff from the adjacent impervious surfaces prior to ultimate discharge at the site.

This is an interesting phenomenon, since the levels of zinc in urban runoff are comparable to the concentrations detected in the discharge from artificial turf fields. It has been well established that urban runoff contains many contaminants such as nutrients, suspended solids, hydrocarbons and heavy metals, including zinc. The average concentration of zinc in urban stormwater runoff has been estimated at 129 ug/l in recent studies (Smullen 1998). EPA's Nationwide Urban Runoff Program (NURP) has collected runoff data and determined that for urban sites the median concentrations of total zinc ranged from 179 -226 ug/l. The National Stormwater Quality Database (NSQD, version 1.1), dated February 16, 2004, compiled zinc concentration data in runoff from various land uses across the United States, which is shown in Table L below.

TABLE I

Land Uses	**Zinc Total (ug/l) Median**
Overall (All Uses)	117
Residential	73
Mixed Residential	99.5
Commercial	150
Mixed Commercial	135
Industrial	210
Mixed Industrial	160
Institutional	305
Freeways	200
Mixed Freeways	90
Open Space	40
Mixed Open Space	88
CT Artificial Turf Stormwater	**84 (mean)**

Since zinc concentrations in the runoff from artificial turf fields are consistent with those associated with urban runoff, it would be a logical step to apply the same best management practices (BMPs) to mitigate the toxicity effects to surface waters. The 2005 Stormwater Management Manual for Western Washington specifically recommends the following BMPs to remove dissolved zinc (and other metals) from stormwater runoff: stormwater treatment wetlands, wet ponds, infiltration structures, compost filters, sand filters and biofiltration structures. The 2004 Connecticut Stormwater Quality Manual suggest the same measures since these treatment practices incorporate biological removal mechanisms that are more effective in removing pollutants than systems that strictly rely on gravity or physical separation of particles in the stormwater. The 2004 Connecticut Stormwater Quality Manual further recommends a treatment train approach, which provides a series of BMPs each designed to provide targeted pollution control benefits.

The University of New Hampshire Stormwater Center has field tested many of these stormwater BMPs that demonstrate significant removal of dissolved zinc. For example, the Retention Pond, Subsurface Gravel Wetland and Bioretention System (Bio II) stormwater treatment measures, over a two year period, removed between 90% and 100% of the soluble zinc, based on a median annual influent Event Mean Concentrations (EMC) of 60ug/l (see Appendix B for fact sheets). The three highest zinc concentrations detected in the stormwater from artificial turf fields in our study were 130, 150 and 260 ug/l, respectively. Assuming 80% removal of zinc from the stormwater prior to discharge to surface waters, all three of the highest zinc concentrations would meet the acute aquatic toxicity criteria (26, 30 and 52 ug/l, respectively). To mitigate the risk to aquatic life and surface waters, the DEP strongly recommends that the aforementioned stormwater best management practices be incorporated into the design of the drainage system for artificial turf fields.

10. ENVIRONMENTAL RISK ASSESSMENT IN RECENT STUDIES

Several other studies were conducted to determine the risk to surface waters and groundwater from the stormwater discharges from artificial turf fields**.** Since artificial turf fields can either discharge to groundwater or surface water, the ecological risks must be evaluated for both potential pathways. This was confirmed by Nillson et al (2008), that drainage from artificial turf fields can enter the environment by either seeping through the underlying soil and potentially contaminate the groundwater, or alternatively, by stormwater runoff entering the adjacent watercourses.

a) Overall Surface Water Contamination Risk

1) Organic Compounds

The studies conducted by Plesser (2004) indicated that concentrations of the common polycyclic aromatic hydrocarbons (PAHs) anthracene, fluoranthene and pyrene, as well as nonylphenols, would exceed the limits for freshwater specified in the Canadian Environmental Quality Guidelines. Torsten (2005) from the Norwegian Institute for Water Research (2005) also predicted that concentrations of alkyl phenols and octylphenol in particular would exceed the limits for environmental effects in the scenario which was allowed a 10:1dilution of run-off. Torsten (2005) further determined that the leaching of chemicals from the materials in the artificial turf system would decrease slowly, so that environmental effects could occur over many years. However, Torsten (2005) anticipated only localized impacts due to the relatively small concentration of the leaching pollutants. The SVOCs analysis of the stormwater in our study, utilizing EPA Method 625, and a specific search for 4-(t-octyl)-phenol, detected no anthracene, flouranthene, pyrene or standard phenol compounds.

Kolitzus (2006) detected no appreciable PAHs concentrations in the runoff analyzed from artificial surface systems. The PAHs that were found above detection limit were ubiquitous substances in the environment. The PAH concentrations in the unbound supporting layer were determined to be in the range of analytic determination limit (0.02 μg/l). The sum of all 16 PAHs was 0.1 to 0.3 μg/l. Similarly, in a recent New York study (Lim et al 2009), no standard organics were detected utilizing EPA Method 624 and 625 in the stormwater sample collected. The

SVOC analysis of the stormwater in our study, utilizing EPA Method 625, detected no standard PAHs.

In surface systems with EPDM and recycled rubber infill, Kolitzus (2006) found several aromatic amino complexes and benzothiazole detected in the range of 10 – 300 μg/l. These concentrations were similar to the results of simulated normal tire wear tests. Lim et al (2009) reported a semi-volatile rubber compound, benzothiazole, at 1,000 ug/l as a Tentatively Identified Compound (TIC) in one stormwater sample. The SVOC analysis of the stormwater in our study, utilizing EPA Method 625, detected no standard aromatic amines, but further TIC analysis did detect identified and unidentified organic compounds. Benzothiazole was detected in two stormwater samples at estimated concentrations of 1.0 and 4.9 ug/l, respectively, which is significantly lower than concentrations found by Lim et al (2009). The Connecticut acute and chronic toxicity benchmark for benzothiazole are 21,333 ug/l and 3,200 ug/l, respectively, based on available toxicity information. The estimated concentrations of benzothiazole are insignificant compared to both the acute and chronic toxicity criteria. Also, a number of unidentified organic compounds were detected during the SVOC TIC analysis at concentrations ranging from 1 ug/l to 150 ug/l, with a median concentration of 6.6 ug/l. The 10/7/09 Field C stormwater sample, which the maximum unidentified compound concentration of 150 ug/l was detected in, was not found to be acutely toxic.

The results from our study appear to be consistent with the results from Kolitzus (2006) and Lim et al (2009), including the detection of benzothiazole in the stormwater samples. Overall, our study did not identify any organic compounds at sufficient concentrations to be considered a potential contamination risk to surface waters.

2) Metals

Based on our analysis of the stormwater collected from the artificial turf fields, zinc is the only metal detected in concentrations which could pose a risk to surface water resources. This finding is consistent with many recent studies which analyzed leachate and stormwater from crumb rubber infill, which indicate that zinc is the primary contaminant of concern coming from artificial turf sites. In sites with limited dilution both the Norwegian Pollution Control Authority (2005) and Verschoor (2007) conclude that the concentration of zinc in the leachate would exceed applicable water quality standards. The Norwegian Pollution Control Authority classifies artificial turf runoff as Environmental Quality Class V (very strongly polluted water) due to the high concentration of zinc in the leachate. The risk assessment conducted by Norwegian Institute for Water Research (2005) shows that the concentration of zinc poses a significant local risk of environmental effects in surface water which receives run-off from artificial turf fields.

Verschoor (2007) also conducted a risk assessment concluding that the estimated concentrations of zinc in the drainage water from artificial football fields to be between 1100-1600 ug/L. This concentration exceeded the Dutch legal criterion for surface water Maximum Permissible Chronic Concentration (MPC) of 40 ug/l by a factor of 27-40. Verschoor explained that drainage water concentrations would be diluted in the receiving surface waters, but indicated that zinc in "small ditches" could exceed MPA (Maximum Permissible Acute). Verschoor espoused a general discharge impact rule that only 10% of the permissible concentration of a contaminant (=

4 ug/l) may be consumed by a particular source. This would imply that the concentration of zinc in smaller receiving water would exceed the water quality criteria by a factor of 45-80. Verschoor identified zinc as a potential eco-toxicological risk to surface water, but did indicate that if the crumb rubber were to be replaced by infill materials with a lower zinc emission, the pollutant concentrations in runoff and adjacent surface water should drop quickly.

Lim et al (2009) conducted a mathematical assessment of the risks to aquatic life from crumb rubber leachate based on the SPLP test results for zinc, aniline and phenol. Based on these concentrations, NYSDEC's Division of Fish, Wildlife and Marine Resources concluded that there may be a potential aquatic life impact due to zinc being release from crumb rubber solely derived from truck tires. However, New York State also concluded that an impact is unlikely if the crumb rubber material is from mixed tires and concentrations of zinc from a column test were used rather than the SPLP. It should be noted, that for the column test to better simulate field conditions, the material in the column must reflect local soil conditions and pH.

Several recent studies analyzed stormwater samples collected from artificial turf fields for metals. Lim et al (2009) and Kolitzus (2006) detected concentrations of zinc at 59.5 ug/l and 20 ug/l, respectively. Milone and MacBroome (2008), conducted field studies and detected zinc in the stormwater from four of the six sampling dates , with a maximum concentration of 31 ug/l which is below acute aquatic toxicity criteria of 65 ug/l.

The zinc concentrations in our stormwater samples were significantly higher than those of Lim, Kolitzus and Milone and MacBroom, with three of the eight the samples tested exceeding acute surface water quality criteria. If not mitigated with appropriate stormwater treatment measures, the zinc concentrations found in our study could contribute to the environmental risk of aquatic organisms in surface waters.

3) Aquatic Toxicity

Wik (2006) studied the toxicity of various tire brands and determined that different formulas for rubber contributed to varying degrees of toxicity in the leachates to *Daphnia magna*. By conducting a toxicity identification evaluation on various tire leachates (EPA 600/6-91/003), Wik determined that although zinc was prevalent, the semi-volatile non polar organics also heavily influenced the toxicity of the resulting leachate. Passing the simulated tire leachates through carbon filters was the only manipulation that consistently reduced toxicity. Compared to the results from Milone and MacBroom (2008), this study reported significantly higher levels of both aquatic toxicity and zinc. This study found that three of the eight stormwater samples tested were acutely toxic to both the invertebrate (*Daphnia pulex*) and the fathead minnow (*Pimephales promelas*). These acutely toxic samples directly coincided with the exceedences of the acute aquatic life criteria for zinc. Consequently, zinc seems to be the primary pollutant of concern. This study indicates that there is risk associated with whole effluent toxicity and zinc.

b) Overall Groundwater Contamination Risk

Stormwater from the fields can impact groundwater directly by percolating through the artificial turf via an "open" underground drainage system (perforated pipes, coarse bedding materials, stone trenches). The stormwater discharges to the underlying soil layers, and ultimately, enters

the ground water. Based on the nature of the underlying soil and the depth to groundwater, the field stormwater is likely to physically and chemically interact with a mineral soil layer (vadose zone) prior to encountering groundwater. This stormwater/soil interaction would be affected by pH, volume of stormwater and soil characteristics, such as moisture, chemistry, mineralogy, soil texture, hydraulic conductivity and drainage class. These interactions would likely influence the concentrations of contaminants found in the groundwater.

There are two primary concerns with the contamination of groundwater in the environment - the threat to drinking water and the threat to surface water resources via groundwater recharge. Several other studies were conducted on the crumb rubber fill from 2004 to 2009; (Plesser(2004), Nillson et al (2008), the Norwegian Institute for Water Research (2005) , Verschoor, A.J., RIVM Report 601774011/2007(2007) Study, (Milone & MacBroom Study 2007),NYSDEC May 2009 an Kolitzus, Hans J. (2006). These studies compared the relative concentration of contaminants found in laboratory leachates and/or artificial turf generated stormwater with various drinking water and aquatic life criteria.

1) Organic Compounds

It should be noted that substances, to a varying degree, will be absorbed by the sand/clay layers which the drainage water passes. Although Nillson et al (2008) found that concentrations of nonylphenols in the contact water from leaching tests were in the order of 20-800 times above the threshold values for drinking water, it was uncertain as to whether this concentration would be significant in the actual groundwater. The EPA aquatic life acute criteria for nonylphenol for freshwater and saltwater resources are 28 ug/l and 7.0 ug/l, respectively. It is important to note that nonyphenol has been associated with the disruption of fish endocrine systems at concentrations below EPA's criteria. No data was available for phthalates and nonylphenols under such realistic conditions from lysimeter data. Nillson determined that the assessment of the impact on water systems also requires more realistic lysimeter tests or measurements on drainage water from artificial turf fields over time.

Plesser (2004) compared leachate results with Canadian Environmental Quality Guidelines for ground water. Groundwater guidelines are developed for both protection of drinking water and protection of surface water via groundwater recharge. Plesser identified anthracene, fluoranthene, pyrene and nonylphenols as compounds in the leachate that could exceed the more protective criteria for groundwater. Plesser also concluded that analyzing possible paths and changes in leaching properties over time is necessary to determine the degree to which the concentrations of these compounds are actually harmful to people and the environment.

Lim et al (2009) conducted a leachate (SPLP) test on rubber crumble material, and analyzed for zinc, phenol and aniline. The results from recent leaching studies indicated a potential for release of aniline, benzothiazole, phenol, and zinc to the groundwater. However, concentrations of the organic contaminants analyzed were below levels that would impose a risk to drinking water. Lim also collected 32 groundwater samples from wells installed downgradient of four artificial turf fields and analyzed them for SVOCs, including aniline and benzothiazole, using SW-846 Method 8270C. The wells were installed in sandy textured soils with depth to the groundwater ranging from 8.3 to 70 feet. All test results were below the limit of detection for all

groundwater samples analyzed. Based on test results of 32 samples, no organics were detected in the groundwater at the turf fields.

Our results are consistent with the leachate and groundwater sampling results in Lim et al (2009). The concentrations of organic compounds in our study did not exceed groundwater protection criteria.

2) Metals

In general, metals are immobilized in soils by adsorption, absorption and precipitation. All of these, mechanisms impede movement of the metals to ground water. Metal-soil interaction is such that when metals are introduced at the soil surface, downward transportation does not occur to any great extent unless the metal retention capacity of the soil is overloaded, or metal interaction with the associated waste matrix enhances mobility.

Zinc is the most prevalent contaminant in the leachate and stormwater studies. In several of these studies, zinc concentrations measured in leachate exceeded drinking water standards. Most of the zinc in soil is absorbed to the soil as zinc hydroxide or oxide and does not dissolve in water. Zinc does show moderate mobility under relatively acid soil conditions (pH 5–7) because of increased solubility and formation of soluble complexes with organic lignands (Elliott et al. 1986; Stevenson and Fitch, 1986; Klamberg et al. 1989). Zinc is retained in an exchangeable form at low pH in iron and manganese oxide dominated soils but becomes non-exchangeable as the pH was increased above 5.5 (Stahl and James, 1991). Therefore, depending on the acidity of the soil and water, some zinc may reach groundwater.

Nillson et al (2008) determined that although leachate concentrations of zinc were in excess of the drinking water quality standards, similar concentrations were not observed in (field) lysimeter tests. Nillson concluded that the concentration of zinc in the lysimeter tests were a more accurate reflection of zinc in the groundwater and, therefore, zinc concentrations would not exceed drinking water standards.

Lim et al (2009) was the only study that did not report concentrations of zinc in the SPLP leachate that exceeded drinking water standards.

Verschoor (2007) concluded that, for the majority of situations, the risks of zinc to public health are minimal since it is not very toxic to humans and the World Health Organization (WHO) drinking water criteria was not exceeded in tests. However, Verschoor (2007) did note that in sandy areas discharges to groundwater may exceed Dutch Intervention Values by a factor of 1.5 to 2.2. In sandy soils, infiltration of water with dissolved zinc will result in weak binding of zinc to the soil matrix and could cause protection criteria to be exceeded by a factor of 12. Verschoor concluded that zinc was a potential eco-toxicological risk to groundwater and soil.

Plesser (2004) and CAES (2009) indicated that zinc was the most likely contaminant to exceed drinking water standards in the leachate. All studies indicate that, although compounds were present in the leachate or stormwater, it was uncertain as to what affect the underlying soils and groundwater would have on the actual concentration of contaminants in the groundwater. Actual groundwater testing may be necessary to determine the impact.

The leachate results reported by CAES showed zinc concentrations up to ten times the drinking water standards and up to 500 times the surface water protection criteria. Our study detected concentrations of zinc in the stormwater significantly lower than CAES results, with no exceedences of drinking water standards and no significant concerns for groundwater quality. It is important to note that no groundwater samples were collected for our study.

11. CONCLUSIONS

The DEP concludes that there is a potential risk to surface waters and aquatic organisms associated with whole effluent and zinc toxicity of stormwater runoff from artificial turf fields. Zinc concentrations in the stormwater may cause exceedences of the acute aquatic toxicity criteria for receiving surface waters, especially smaller watercourses. The DEP suggests that use of stormwater treatment measures, such as stormwater treatment wetlands, wet ponds, infiltration structures, compost filters, sand filters and biofiltration structures, may reduce the concentrations of zinc in the stormwater runoff from artificial turf fields to levels below the acute aquatic toxicity criteria. Individual artificial turf field owners may want to evaluate the stormwater drainage systems at the fields and the hydrologic and water quality characteristics of any receiving waters to determine the appropriateness of a stormwater treatment measure.

This study did not identify any significant risks to groundwater protection criteria in the stormwater runoff from artificial turf fields. It is important to note, that the DEP study did not directly collect and analyze groundwater at these artificial turf fields. Consequently, this conclusion regarding consistency with groundwater protection criteria is an extrapolation of the stormwater results collected and the evaluation of data presented in recent studies, such as Nillson et al (2008) and Lim et al (2009). To make a final conclusion regarding the overall risk from exposure to groundwater affected by stormwater runoff from artificial turf fields, further sampling and analysis of groundwater at the artificial turf fields would be required.

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Athletic Playing Fields and Artificial Turf: Considerations for Municipalities and Institutions

This fact sheet introduces some of the considerations that are relevant to evaluating natural grass and artificial turf playing surfaces. For more of TURI's research on artificial turf and natural grass, see www.turi.org/artificialturf.

Principles of toxics use reduction

TURI's work is based on the principles of toxics use reduction (TUR). The TUR approach focuses on identifying opportunities to reduce or eliminate the use of toxic chemicals as a means to protect human health and the environment. Projects to reduce the use of toxic chemicals often have additional benefits, such as lower life-cycle costs.

Children's environmental health

People of all ages benefit from a safe and healthy environment for work and play. However, special concerns exist for children. Children are uniquely vulnerable to the effects of toxic chemicals because their organ systems are developing rapidly and their detoxification mechanisms are immature. Children also breathe more air per unit of body weight than adults, and are likely to have more hand-to-mouth exposure to environmental contaminants than adults.[1] For these reasons, it is particularly important to make careful choices about children's exposures.

Artificial turf and chemicals of concern

Artificial turf has several components, including drainage materials, a cushioning layer, synthetic grass carpet (support and backing materials and synthetic fibers to imitate grass blades), and infill that provides cushioning and keeps grass carpet blades standing upright. Here, we briefly review issues related to chemicals in synthetic grass carpet and infills.

Crumb rubber infill made from recycled tires. Crumb rubber made from recycled tires is widely used as infill. This material is also referred to as styrene butadiene rubber (SBR), or as tire crumb. Many peer-reviewed studies have examined the chemicals present in tire crumb. Tire crumb contains a large number of chemicals, many of which are known to be hazardous to human health and the environment. These include polyaromatic hydrocarbons (PAHs); volatile organic compounds (VOCs); metals, such as lead and zinc; and other chemicals.[2–5] Some of the chemicals found in tire crumb are known to cause cancer. [6–8] Because of the large number of chemicals present in the infill, as well as the health effects of individual chemicals, crumb rubber made from recycled tires is the option that likely presents the most concerns related to chemical exposures.

Other synthetic infills. Other synthetic materials used to make artificial turf infill include ethylene propylene diene terpolymer (EPDM) rubber, thermoplastic elastomers (TPE), waste athletic shoe materials, and acrylic-coated sand, among others. These materials also contain chemicals of concern, although the total number of chemicals and/or the concentration of chemicals of concern may be lower in many cases.[5] For more information on chemicals in these materials, see TURI's report, *Athletic Playing Fields: Choosing Safer Options for Health and the Environment*.[9]

Mineral-based and plant-derived materials. Other materials used as infill can include sand, zeolite, cork, coconut hulls, walnut shells, olive pits, and wood particles, among other materials. These materials are likely to contain fewer hazardous chemicals than tire crumb, but many of the materials have not been well characterized or studied thoroughly.[5] Some plant-based materials may raise concerns related to allergies or respirable fibers. In addition, zeolite and sand can pose respiratory hazards. Exposure to some types of zeolites may be associated with increased risk of developing mesothelioma, a type of cancer.[10,11] Using zeolite can be considered a regrettable substitution. For sand, it is important to understand the source and type of the material; industrial sand that is freshly fractured or that has been highly processed to contain very small particles can be a respiratory hazard when inhaled.[5]

Synthetic grass carpet. Toxic chemicals such as lead are also found in the artificial grass blades in some cases. [6,7] Recent research has identified per- and poly-fluoroalkyl substances (PFAS) in some artificial turf carpet materials. PFAS are a group of chemicals that are highly persistent in the environment. PFAS do not break down under normal environmental conditions, and some can last in the

environment for hundreds of years or longer. As a result, introducing these chemicals into the environment has lasting consequences. Health effects documented for some PFAS include effects on the endocrine system, including liver and thyroid, as well as metabolic effects, developmental effects, neurotoxicity, and immunotoxicity. For more information, see TURI's fact sheet, "Per- and Poly-fluoroalkyl Substances (PFAS) in Artificial Turf Carpet." [12]

Artificial turf and heat stress

In sunny, warm weather, artificial turf can become much hotter than natural grass, raising concerns related to heat stress for athletes playing on the fields. Elevated surface temperatures can damage equipment and burn skin, and can increase the risk of heat-related illness.[13] Heat-related illness can be a life-threatening emergency. Experts note that athletic coaches and other staff need to be educated about heat-related illness and understand how to prevent it, including cancelling sport activities when necessary. [14,15]

Research indicates that outdoor synthetic turf reaches higher temperatures than natural grass, regardless of the infill materials or carpet fiber type.[13] The Penn State Center for Sports Surface Research measured surface temperature for infill alone, artificial grass fibers, and a full synthetic turf system. The study included several types and colors of infill and fibers. They found that all the materials reached high temperatures than grass when heated indoors (with a sun lamp), or outdoors.

Irrigation can lower field temperature for a short time. A Penn State study found that frequent, heavy irrigation reduced temperatures on synthetic turf, but temperatures rebounded quickly under sunny conditions. [16] Other studies found similar results. [17]

Approaches to determining safe temperatures for recreational field spaces. Several methods are available for measuring heat in a play area. It is sometimes necessary to use more than one method in order to determine whether conditions are safe for exercise or play.

One heat metric, Wet Bulb Globe Temperature (WBGT), takes into account ambient air temperature, relative humidity, wind, and solar radiation from the sun. WBGT can help to guide precautions such as rest, hydration breaks, and cancellation of sports activities. However, WBGT may does not take account of field surface temperature.

Another approach is to measure the temperature of the playing field surface itself. One researcher has noted that artificial turf surface temperatures are not captured by either a heat advisory or by wet bulb temperature, and that "elevated risk of heat stress can stem from infrared heating from the ground, regardless of the air temperature." Thus, the researcher suggests, greater caution regarding heat is needed when athletes are playing on artificial turf, "even if the air temperature is not at an otherwise unsafe level." [18]

WBGT is used as the basis for a heat policy adopted by Massachusetts Interscholastic Athletic Association (MIAA) in 2019. This policy requires schools to select a method to monitor heat during all sports related activities, and modify activities as needed to protect student athletes.[19] The MIAA policy does not provide guidelines based on the type of playing surface, and does not take account of surface temperature specifically.

The school board of Burlington, MA has taken additional steps to protect student athletes by ensuring that both WBGT and surface temperature are taken into account.[20] Burlington's policy, "Utilizing Artificial Turf in the Heat," requires use of an infrared heat gun to determine field surface temperature. The policy includes information about the conditions under which athletes may use artificial turf fields and the conditions under which their activities must be moved to grass fields. For example, the policy states that if the National Weather Service issues a Heat Advisory, artificial turf cannot be used for physical education if the air temperature is higher than 85 degrees with humidity 60 percent or more. Under these conditions, only a grass surface may be used. The policy also lays out criteria to be taken into account in determining activity levels. For example, when air temperature is below 82 degrees, activities are permitted on artificial turf up to a surface temperature of 120 degrees, with three water breaks per hour. Above this surface temperature, activities must be moved to a grass field.

Injuries

Studies show variable outcomes in the rates and types of injuries experienced by athletes playing on natural grass and on artificial turf. [6,21,22] Among recent studies and reviews of studies, several suggest an increase in foot and/or ankle injuries on artificial turf as compared with natural grass[23–25]; several find no difference[26]; and one suggests a possibly lowered risk on artificial turf.[27] All of these studies recommend further evaluation of this question.

One particular concern is increased rates of turf burns (skin abrasions) associated with playing on artificial turf. For example, a study by the California Office of Environmental Health Hazard Assessment found a two- to three-fold increase in skin abrasions per player hour on artificial turf compared with natural grass turf.[6] The study authors noted that these abrasions are a risk factor for serious bacterial infections, although they did not assess rates of these infections among the players they studied.

Environmental concerns

Environmental concerns include loss of wildlife habitat, migration of synthetic particles into the environment, and contaminated stormwater runoff. A study by the Connecticut Department of Environmental Protection identified concerns related to a number of chemicals in stormwater runoff from artificial turf fields. They noted high zinc concentrations in

stormwater as a particular concern for aquatic organisms. They also noted the potential for leaching of high levels of copper, cadmium, barium, manganese and lead in some cases. The top concerns identified in the study were toxicity to aquatic life from zinc and from whole effluent toxicity (WET).[28] WET is a methodology for assessing the aquatic toxicity effects of an effluent stream as a whole.[29] In addition, scientists have raised concerns about the contribution of artificial turf materials to microplastic pollution.[30–32]

Safer alternative: organically managed natural grass

Natural grass fields can be the safest option for recreational space, by eliminating many of the concerns noted above. Natural grass can also reduce overall carbon footprint by capturing carbon dioxide. Grass fields may be maintained organically or with conventional or integrated pest management (IPM) practices. Organic turf management eliminates the use of toxic insecticides, herbicides and fungicides.

Organic management of a recreational field space requires a site-specific plan to optimize soil health. Over time, a well-maintained organic field is more robust to recreational use due to a stronger root system than that found in a conventionally managed grass field. Key elements of organic management include the following.[33]

- **Field construction**: Construct field with appropriate drainage, layering, grass type, and other conditions to support healthy turf growth. Healthy, vigorously growing grass is better able to out-compete weed pressures, and healthy soil biomass helps to prevent many insect and disease issues.
- **Soil maintenance**: Add soil amendments as necessary to achieve the appropriate chemistry, texture and nutrients to support healthy turf growth. Elements include organic fertilizers, soil amendments, microbial inoculants, compost teas, microbial food sources, and topdressing as needed with high-quality finished compost.
- **Grass maintenance**: Turf health is maintained through specific cultural practices, including appropriate mowing, aeration, irrigation, and over-seeding. Trouble spots are addressed through composting and re-sodding where necessary. Aeration is critical because it makes holes in the soil that allow more air, water and nutrients to reach the roots of the grass and the soil system. Stronger roots make the grass better able to naturally fend off weeds and pests. Aeration also breaks up areas of compacted soil.

Massachusetts communities investing in organic grass fields. In Massachusetts, the city of Springfield and the town of Marblehead have both been successful in managing athletic fields organically. These communities' experiences are documented in case studies.[34,35] In addition, the Field Fund in Martha's Vineyard has invested in organic maintenance of a number of athletic fields and has documented the process at www.fieldfundinc.org.

Installation and maintenance costs: comparing artificial turf with natural grass

In analyzing the costs of artificial vs. natural grass systems, it is important to consider full life-cycle costs, including installation, maintenance, and disposal/replacement. Artificial turf systems of all types require a significant financial investment at each stage of the product life cycle. In general, the full life cycle cost of an artificial turf field is higher than the cost of a natural grass field.

Cost information is available through university entities, turf managers' associations, and personal communications with professional grounds managers. Information is also available on the relative costs of conventional vs. organic management of natural grass.

Installation. According to the Sports Turf Managers Association (STMA), the cost of installing an artificial turf system may range from $4.50 to $10.25 per square foot. For a football field with a play area of 360x160 feet plus a 15-foot extension on each dimension (65,625 square feet), this yields an installation cost ranging from about $295,000 to about $673,000. These are costs for field installation only, and full project costs may be higher. Costs for a larger field would also be higher.

In one site-specific example, information provided by the town of Natick, Massachusetts shows that the full project budget for the installation in 2015 of a new artificial turf field (117,810 square feet), along with associated landscaping, access and site furnishings, totaled $1.2 million.[36]

For natural grass, installation of a new field may not be necessary. For communities that do choose to install a new field, costs can range from $1.25 to $5.00 per square foot, depending on the type of field selected. For the dimensions noted above, this would yield an installation cost ranging from about $82,000 to about $328,000.[37] However, in many cases communities are simply able to improve existing fields.

Maintenance. Maintenance of artificial turf systems can include fluffing, redistributing and shock testing infill; periodic disinfection of the materials; seam repairs and infill replacement; and watering to lower temperatures on hot days. Maintenance of natural grass can include watering, mowing, fertilizing, replacing sod, and other activities. Communities shifting from natural grass to artificial turf may need to purchase new equipment for this purpose. According to STMA, maintenance of an artificial turf field may cost about $4,000/year in materials plus 300 hours of labor, while maintenance of a natural grass field may cost $4,000 to $14,000 per year for materials plus 250 to 750 hours of labor.[37]

Springfield, MA manages 67 acres of sports fields, park areas, and other public properties organically. Field management costs in 2018, including products, irrigation maintenance, and all labor costs, were just under $1,500 per acre across all of the properties.[34]

Natural grass maintenance: Conventional vs. organic costs. Organic turf maintenance can be cost-competitive with conventional management of natural grass. One study found that once established, an organic turf management program can cost 25% less than a conventional turf management program.[38]

Disposal/replacement. Artificial turf requires disposal at the end of its useful life. STMA estimates costs of $6.50 to $7.80 per square foot for disposal and resurfacing.[37] Those estimates yield $426,563–$511,875 for a 65,625 square foot field and $552,500–$663,000 for an 85,000 square foot field.

Disposal is an increasing source of concern. Used synthetic turf is projected to produce between 1 million and 4 million tons of waste over the next decade, but there is a lack of plans or guidance for its disposal.[39,40] In most cases it cannot be completely recycled, and disposing of it in landfills is expensive and not an industry best practice, according to one article.[39] Used turf that is dumped illegally near a body of water can attract pests, and piles can pose a fire risk.[39]

Life-cycle costs. In 2008, a Missouri University Extension study calculated annualized costs for a 16-year scenario. The calculation included the capital cost of installation; annual maintenance; sod replacement costing $25,000 every four years for the natural fields; and surface replacement of the synthetic fields after eight years. Based on this calculation, a natural grass soil-based field is the most cost effective, followed by a natural grass sand-cap field, as shown in the table below.[41] Another study, conducted by an Australian government agency, found that the 25-year and 50-year life cycle costs for synthetic turf are about 2.5 times as large as those for natural grass.[42]

Table 1: Comparison of life-cycle costs

Field type	16-year annualized costs
Natural soil-based field	$33,522
Sand-cap grass field	$49,318
Basic synthetic field	$65,849
Premium synthetic field	$109,013

Source: Brad Fresenburg, "More Answers to Questions about Synthetic Fields – Safety and Cost Comparison." University of Missouri.

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Natural Grass Playing Field Case Study: Marblehead, MA

20 Acres of Organically Managed Playing Fields

THE TOWN OF MARBLEHEAD, Massachusetts, has managed all of its playing fields organically since 2002. This approach had its origins in a policy adopted by Marblehead's Board of Health in 1998, which noted the adverse health and environmental effects of pesticides and made a commitment to protecting children's health.

The town has achieved its performance goals by focusing on building and maintaining a healthy ecosystem with active microbial life in the soil and a strong root system. Key elements of the program are frequent aeration, frequent mowing, soil testing, and the use of organic fertilizer and soil amendments.

Organically managed fields at Veterans' Middle School located in Marblehead, MA

This case study provides detailed information on the number of hours played at four multi-use fields in Marblehead. Each of these fields may serve as a useful model for other communities interested in organic field management. For example, the Seaside Park field is used for baseball and field hockey. The scheduled practice and play time on this 105,000 square foot field totaled about 1,180 hours in 2018. With estimated informal recreation included, the field was used for approximately 1360 hours.

The annual cost of organic management of Marblehead's fields, including products, mowing, aeration, and other activities, is approximately $4,250 - $4,500 per acre.

Marblehead also has one artificial turf field, installed in 2013. Information is provided on maintenance costs for the artificial turf field, including grooming, cleaning, compaction testing, decompaction, and disinfection.

July 2019 (Revised November 2020)

TURI
TOXICS USE REDUCTION INSTITUTE
UMASS LOWELL

Introduction

This case study has been developed by the Toxics Use Reduction Institute (TURI) as part of an effort to provide information to municipalities, schools and other institutions as they make decisions about play surfaces. TURI has documented information on the materials often used in artificial turf playing fields.[1] TURI has also gathered information on natural grass fields and has developed a series of case studies to share experiences.

This case study focuses on the organic management of natural grass on 20 acres of sports fields by the town of Marblehead. The organic practices described in this case study can be used on grass properties of any size.

Communities often have questions about whether natural grass can meet their recreation needs and be cost-effective. TURI has compiled the following information for other communities to learn from the successes of Marblehead.

Overview

In 1998, the Board of Health of the Town of Marblehead adopted a statement on pesticides that enumerated the adverse health and environmental effects of pesticides, with a particular emphasis on children's health. In this statement, the Board of Health made a commitment to phasing out pesticide use, stating: "The Board of Health of the Town of Marblehead hereby commits itself to the goal of reduction and eventual phase-out of pesticide use in the Town of Marblehead, both on public and private property."[2]

With support from a TURI grant, in 1999-2000 Marblehead developed the state's first municipal organic lawn demonstration site, serving as a resource for residents interested in alternatives to pesticides. The town also developed the state's first organic pest management policy,[3] and served as host to a wide variety of educational programs for landscapers, homeowners and others. Building on this commitment, Marblehead began organic management of all its publicly managed land, including sports fields. All of Marblehead's fields have been managed organically since 2002.

Marblehead currently has twenty acres of publicly owned grass fields, all of them managed organically. This total area includes both grass and skinned surfaces (i.e., clay in infield areas of baseball and softball fields).

Specifically, the fields include the following: five little-league baseball fields; four girls' softball fields; three all-purpose fields (soccer, lacrosse, youth football, and other activities); one 90-foot regulation baseball field where the outfield is also used for field hockey; one 90-foot regulation baseball field where the outfield is also used for all-purpose practice, including football; and additional areas used for informal recreation, including a neighborhood pocket park. [4] The town is also planning to build a new, fully renovated field, which will be organically managed from the outset.

[1] Massachusetts Toxics Use Reduction Institute (TURI). 2018. *Athletic Playing Fields: Choosing Safer Options for Health and the Environment.* TURI Report #2018-002. Retrieved from www.turi.org/artificialturfreport

[2] Town of Marblehead Board of Health. 1998. *Statement on Pesticides, May 14, 1998.* Retrieved from www.turi.org/Our_Work/Community/Topic_Areas/Pesticides/Marblehead_Organic_Lawn_and_Garden_Demonstration_Project/Project_Materials/Town-Statement-on-Pesticides

[3] Town of Marblehead Board of Health. 2001. Organic Pest Management Policy for Turf and Landscape, May 3, 2001.

[4] 90-foot refers to the distance in feet between bases. This is a standard baseball field size.

This case study focuses on four of the athletic fields in Marblehead, as shown in Table 1. The Seaside Park field is a well-designed park with good drainage and few maintenance difficulties; the Hopkins Field is a high-use park; the Veterans' Middle School field is used for physical education and recess and was used for field hockey in the past; and the Village School Lower Field back half field is a field with very high use and some design problems. This case study helps to illustrate the successes of a 100% organic management program, as well as the ways in which the grounds managers have overcome specific difficulties that can be faced by many communities using or renovating existing fields.

Table 1: Marblehead athletic fields included in this case study[a]

Park	Area (sq. ft.)[b]	Sports/other information
Seaside Park	105,000	Fitness trail, cross country meets, conditioning, baseball (adult & youth), field hockey
Hopkins Field	65,000	Football, soccer, lacrosse, middle school physical education
Veterans' Middle School field	90,000	Girls' youth softball, high school softball, middle school physical education, middle school advisory, high school field hockey, youth flag football, middle school ultimate Frisbee[c]
Village School Lower Field back half	65,340[d]	High school lacrosse, boys' youth lacrosse, youth soccer, middle school recess, high school soccer, youth soccer

[a] Marblehead has 20 acres of athletic fields, all of them managed organically. This table only shows the fields for which detailed information is provided in this case study.

[b] Area shown is total for grass only.

[c] Advisory is an activity break in which the students play outdoor games and do team-building activities

[d] The full Village School field is 3 acres, but the section covered in this case study is 1.5 acres (65,340 sq. ft.).

Hours of Activity: Examples from Four Sports Fields

Decision-makers often have questions about how many hours of use a natural grass field can accommodate. Marblehead documented the use of their athletic fields in 2018. Total hours of use are presented for each activity and age group, and include practice and games for sports. Hours of use per season were estimated by multiplying the number of hours booked for each activity by the number of weeks each activity was played per season.

These fields are also used by Marblehead residents for informal activities, such as pick-up games, or passive recreation, such as picnics. These activities take place during open park hours that have not been scheduled for team use, or on areas of the complex that are not in use during formally scheduled activities. In the absence of data on informal activities, TURI estimated that each case study park was used an additional 14 hours per week for informal/unscheduled activity.

Cancellations

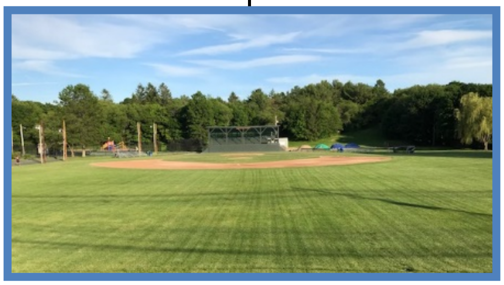
Marblehead chooses to cancel games when there is standing water on fields. Notifications are sent by email to residents. Youth groups have learned about the importance of preserving the grass in good condition; the youth are protective of the fields and careful not to play when they are too wet. In 2018, between April 1 and November 15, the fields were closed five times due to rain and twice due to extreme heat. Each was a one-day closure. The heat-related closures were the first that the town has experienced.

Seaside Park: Baseball and Field Hockey Field within a Larger Park

Seaside Park is a 34-acre park that offers a network of walking trails as well as a play area, including a baseball diamond, a playing field, tennis courts, basketball courts, and other resources. The baseball field is a regulation 90-foot baseball field. The outfield of the 90-foot regulation baseball diamond is also used for field hockey. The total grass area is 105,000 square feet.

The fitness trail and part of the field space are used for cross-country meets. Several teams use the fitness trail for conditioning as well.

Youth and high school baseball are played on the field in the spring and summer, and field hockey is played on the field in the fall. In 2018, there were about 1,180 scheduled hours of practice and play on the field.[5] Adding estimated informal recreation time in the summer months, the estimated total is about 1,360 hours of use. This total does not account for the five day-long closures that occurred in 2018.



Baseball and field hockey fields at Seaside Park

Table 2: Seaside Park baseball and field hockey complex: hours of use, 2018

Sport	Age group	Season	Total use: hours per week	Weeks per season	Approximate hours per season[a]
Baseball	Youth	Spring	31	13	400
	High school	Spring	20	13	260
	Youth	Summer	35	9	320
Field hockey	Middle school	Fall	15	13	200
Total scheduled use – all seasons					**1180**
Estimated informal recreation hours (summer only)			14	13	180
Estimated total hours – all seasons					**1360**

Note: Hours shown here do not account for cancellations. In 2018, there were five day-long closures of Marblehead fields due to rain and two due to heat.
[a] Totals rounded to the nearest 10.

Hopkins Field: Full-Sized Football Field

Hopkins Field is a full-sized football field surrounded by a track. The total grass area is 65,000 sq. ft. The field is used for soccer, lacrosse, and middle school physical education in the spring, and soccer, football, and middle school physical education in the fall. Other youth soccer-related activities are also scheduled weekly between the end of June and the end of August. In 2018, there were about 1,680 hours of scheduled practice and play on the Hopkins Field. Adding estimated informal recreation time in the summer months, the estimated total is about 1,860 hours of use, not accounting for the five day-long closures that occurred in 2018.

When organic management of Hopkins Field began in 2004, 35% of the field was covered in weeds,

[5] In summer 2019, the Seaside playing field was temporarily shut down for improvements, allowing only one third of the season to be played on this field.

primarily broadleaf plantain. The high percentage of weeds was due to compaction of the fields. Compaction led to low oxygen levels, creating anaerobic conditions that fostered the growth of microbes that were not conducive to a healthy root system for the grass. The situation was reversed over time through the application of organic techniques.

Hopkins Field, a full-sized football field

Table 3: Hopkins Field full-sized football field: hours of use, 2018

Sport	Age group	Season	Total use: hours per week	Weeks per season	Approximate hours per season[a]
Lacrosse	Youth	Spring	21	13	270
Soccer	Youth	Spring	8	13	100
Soccer	Adult	Spring	4	13	50
Phys Ed	Middle School	Spring	30	8	240
Soccer	High School	Fall	17.5	13	230
Soccer	Youth	Fall	11.5	13	150
Soccer	Adult	Fall	2	13	30
Football	Youth	Fall	13.5	13	180
Phys Ed	Middle School	Fall	30	8	240
Other youth soccer activities (summer only)					190
Total scheduled use – all seasons					**1,680**
Estimated informal recreation hours (summer only)			14	13	180
Estimated total hours – all seasons					**1,860**

Note: Hours shown here do not account for cancellations. In 2018, there were five day-long closures of Marblehead fields due to rain, and two due to heat.
[a] Totals rounded to the nearest 10.

Veterans' Middle School Field: Softball Diamonds and Playing Field

The Veterans' Middle School field consists of two softball diamonds, one with an extended outfield. Together, these fields have an area of 90,000 square feet of grass.[6] In the spring, the field is used for high school and youth softball, and middle school physical education and school advisory. In the fall, the field is used for high school field hockey, youth flag football, middle school ultimate Frisbee, and middle school physical education and advisory.[7] During the summer in 2018, the field was used 189 hours for additional youth soccer activities. A total of about 2,140 hours of practice and play were scheduled on the field in 2018. Including estimated informal recreation, the field complex was used for about 2,320 hours.

[6] Each softball infield is 8,000 square feet. There is some sharing of outfields.
[7] Advisory is an activity break in which the students play outdoor games and do team building activities.

Table 4: Veterans' Middle School Field two softball diamonds and overlapping playing field: hours of use, 2018					
Sport	Age group	Season	Total use: hours per week	Weeks per season	Approximate hours per season[b]
Softball	High school	Spring	34	13	440
Softball	Youth	Spring	55	13	720
Phys ed	Middle school	Spring	30	8	240
Advisory	Middle school	Spring	5	8	40
Field Hockey	High school	Fall	15	13	200
Flag Football	Youth	Fall	10	14	140
Phys Ed	Middle school	Fall	30	10	300
Advisory[a]	Middle school	Fall	5	10	50
Ultimate Frisbee	Middle school	Fall	1	6	6
Total scheduled use – all seasons					**2,140**
Estimated informal recreation hours (summer only)			14	13	180
Estimated total hours – all seasons					**2,320**

Note: Hours shown here do not account for cancellations. In 2018, there were five day-long closures of Marblehead fields, and two due to heat.

[a] Advisory is an activity break in which the students play outdoor games and do team-building activities.

[b] Totals rounded to the nearest 10.

To aid in comparing the activity level on this field with fields in other communities, it may be helpful to consider the softball activities separately from other activities that occur on the field. The softball hours on the two diamonds total about 1,160 hours, or an average of about 580 hours per field (although there is some overlap of the outfields). Other scheduled field activities total about 980 hours.

Table 5: Veterans' Middle School Field: Subtotals of scheduled hours	
Softball only	1160
All other scheduled field activities	980

Village School Lower Field Back Half: Two U10 Soccer Fields[8]

The Village School Lower Field back half is equivalent in size to two soccer fields for age group U10, or one full sized, plus a quarter sized field. The total area is 65,340 square feet.[9] For practices, the field can accommodate four teams simultaneously; for games, it accommodates fewer teams. The field is used for youth soccer in the spring and fall, boys' lacrosse in the spring, high school soccer in the fall, and middle school recess in both fall and spring. In the summer, the field is scheduled for other youth soccer-related activities for just over 300 hours and use by a medical sports clinic for 380 hours. Thus, in spring, summer and fall 2018, a total of 2030 hours of practice, games, and recess were scheduled on the field. In addition, there were an estimated 180 hours of informal use, leading to an estimated total of 2210 hours for all seasons.

[8] U10 is a soccer age group classification of 10 years and under

[9] The full Village School field measures 3 acres, but the section covered in this case study is 1.5 acres (65,340 sq. ft.).

Table 6: Village School Lower Field back half two U10 soccer fields: hours of use, 2018					
Sport	**Age group**	**Season**	**Total use: hours per week**	**Weeks per season**	**Approximate hours per season[a]**
Soccer	Youth	Spring	32	13	410
Lacrosse	Youth	Spring	9	13	120
Soccer	High school	Fall	18	13	230
Soccer	Youth	Fall	25	13	330
Recess	Middle school	Spring, fall	7	37	250
Other youth soccer activities (summer only)					310
Medical sports clinic (summer only)					380
Total scheduled use – all seasons					**2030**
Estimated informal recreation hours (summer only)			14	13	180
Estimated total hours – all seasons					**2210**

Note: Hours shown here do not account for cancellations. In 2018, there were five day-long closures of Marblehead fields due to rain, and two due to heat.
[a] Totals rounded to the nearest 10.

Maintenance

The elements of field maintenance include mowing, aeration and application of products such as fertilizer and soil amendments. Field areas with extra heavy use, such as in front of soccer goals, are also "over-seeded" with grass seeds to allow fuller plant grown to withstand more wear.

Chip Osborne, Chair of the Marblehead Recreation and Parks Commission, designed the maintenance and testing protocols for the fields. He uses soil testing to determine the appropriate amount of products to use and the most effective maintenance approach for individual fields. This eliminates over-application of products and allows the town to adjust maintenance according to the performance needs of each field. Soil testing measures several characteristics of soil, including nutrients (such as nitrogen, potassium, and phosphorus), physical elements (such as soil texture), and biologicals (such as nematodes).

Marblehead has divided field management practices into three tiers according to intensity of use. Tier 1 fields (totaling 12 acres) receive the top level of management for heavy sports use; Tier 2 fields (totaling four acres) receive the same amount of mowing but half of other maintenance activities; and Tier 3 fields (totaling four acres) receive mowing only, with occasional fertilizer.

Over the years, the Marblehead field manager has experimented with a variety of approaches to optimize soil health and grass quality. The details described here represent the current approach, but can be varied.

Fertilizers and Soil Amendments

Marblehead uses organic fertilizers and soil amendments from PJC Organics, a small consulting company and fertilizer producer/distributor in Massachusetts. Amount of product ordered and their application schedules for each park are based on soil results along with the performance needs of each individual field.

The fields are fertilized four times a year with a granular fertilizer at a low dose. These granular applications are carried out in late April, mid-June, late August, and early October. In addition to the granular applications, there are three liquid

fertilizer applications, in June, August, and early October.

The industry standard for use of granular fertilizers on a conventionally managed field is one pound of nitrogen per 1,000 square feet for each application. Because Marblehead uses soil testing to estimate the amount of fertilizer needed for individual fields, the most heavily used fields receive 3/4 pound of fertilizer per 1000 square feet for each application. For fields with lighter use, such as some of the baseball fields, a smaller amount of nitrogen is used.

A mycorrhizal inoculation and a biological supplement are also added to certain fields in June and August. The mycorrhizal inoculation strengthens the system of beneficial fungi that colonize root systems and supports healthy plant growth.

Marblehead field managers also add a soil conditioner to fields to jump-start microbial activity. The soil conditioner is made with biochar (charcoal), kelp, molasses, and soybean and is used to improve the chemistry, structure, and biological activity in the soil.

Aeration, Mowing, and Irrigation

Aeration is accomplished by pulling up plugs of soil and grass using a riding or push machine. This process relieves soil compaction and grass thatching and allows air, water, and added nutrients to penetrate the soil. Aeration can be a time-consuming process, but is arguably the most important step for maintaining healthy, organic grass.

The groundskeeping crew uses two types of aerators interchangeably throughout the year to penetrate 4 inches into the soil. One is a hydraulic core aerator, and the other is a shatter-tine aerator. The crew aims to aerate the fields five times a year, although some years they aerate four times depending on staff availability and weather.

Mowing frequency changes throughout the year. Fields are mowed once a week, except during the peak grass growing season in July, August and September, when fields are mowed twice a week. Fields are irrigated once a week for 26 weeks.

Community Participation in Field Rehabilitation

At the beginning of the organic management program for Seaside Park, the density of weeds was high. This was reversed using organic techniques over the course of five years. The last stage of the field's rehabilitation occurred when a number of weed species had already been reduced and knotweed was the only remaining weed of concern in the field. This was addressed through mechanical means: The girls’ hockey team, a group of 40 players, spent several hours walking systematically across the field and pulling up all the knotweed. The next day, the field was aerated and seeded, and grass grew to fill in the spaces created by removing the knotweed. In this way, the team was able to participate in the management of the field, and the weeds were removed without using herbicides.

Costs

The principal costs associated with organic maintenance of fields in Marblehead cover products, labor for organic management activities such as aeration, and labor for mowing.

Annual product costs, including fertilizer and soil amendments, are typically $1,500 - $1,750 per acre, or $30,000 - $35,000 for the full 20 acres.

A dedicated Turf Specialist with a salary (including benefits) around $75,000 per year was responsible for aerating, seeding, applying fertilizer and soil amendments to the fields. The Turf Specialist spent slightly under half of annual work time on these activities, costing around $34,400.[10] Separate staff members were responsible for mowing all 20 acres 25 times per year. Average salary for these staff members was $60,000 (including benefits). Mowing one acre took around 50 minutes, plus 25 minutes additional time for staging (travel, set-up, break-down). Thus, total labor costs for mowing were approximately $20,500 for the year. This brings the total cost for products and labor per acre to $4,250 - $4,500 per year.

Table 7: Estimated annual costs associated with organic management of 20 acres of athletic fields in Marblehead, MA

Cost category	Costs per acre	Total costs (20 acres)
Products (e.g. fertilizer, soil amendments)	$1,500 - $1,750	$30,000 - $35,000
Maintenance labor (e.g. aeration, other activities)	$1,720	$34,400
Mowing labor	$1,030	$20,500
Annual total for 20 acres of athletic fields	**$4,250- $4,500**	**$84,900 - $89,900**

Note: Cost values were revised in November 2020 based on information provided by Marblehead Recreation and Parks.

Artificial Turf

For a maintenance and cost comparison, TURI also gathered information on Marblehead's 1.5-acre (65,340 square foot) synthetic turf field. [11] The field was installed in 2013; funding of $1.3 million was obtained privately for this project, and youth leagues pay a per-player fee to help support maintenance costs. Maintenance for the synthetic turf field requires grooming, cleaning, compaction testing, and decompaction.

The cost information presented here refers only to field maintenance, not to the initial acquisition and installation of the field. For detailed information on both acquisition and maintenance costs, see TURI's sports turf alternatives assessment cost analysis.[12]

For field maintenance, the town made a capital investment of between $10,000 and $14,000 for a Gator utility vehicle, and $7,500 for a brusher to attach to it. The field is groomed by an in-house Marblehead Recreation and Parks Department staff member who spends about a half day every three weeks in the spring and fall and every four weeks in the summer. That equates to $1,000 - $1,400 in labor costs (including fringe).

Marblehead received a bid for a disinfection product that contains several potential human carcinogens. For two applications per year, the total annual disinfection bid was $6,000. A less toxic, enzyme-based treatment could be provided for a higher cost, but specific figures are not available for this option. Assuming use of the lower-cost disinfection option, total annual costs for the 1.5-acre field add up to $7,000 - $7,400, not

[10] The Turf Specialist's time allocated to field maintenance was estimated for the time periods April-June, July-August, and September-October at 90%, 65%, and 75%, respectively, for an annual total of approximately 46% time.

[11] Marblehead All Sports Foundation. Web page available at marbleheadallsports.com/track/masf/.

[12] Sports Turf Alternatives Assessment: Preliminary Results Cost Analysis. Toxics Use Reduction Institute. 2016. Available at turi.org/artificialturf.

including up-front capital costs for field installation or maintenance equipment.

To gain more information on cost options, the town of Marblehead obtained a cost quote for synthetic turf maintenance performed entirely by an outside contractor. For two maintenance visits per year (including grooming, cleaning, de-compacting, field inspection, impact testing and infill depth measurements) the total cost would be $5,300 per year. A higher cost option would provide six visits per year, with disinfectant applied at each visit, as well as minor repairs. This option is offered for $6,800 per year for maintenance of the 1.5-acre field. Other costs to consider include those associated with disposal and replacement of synthetic turf surfacing and padding after 8-10 years of wear.

Summary

Marblehead has maintained high quality, organically managed grass fields throughout the community over a period of more than 15 years. Young athletes are invested in the goal of protecting and maintaining their fields, and take pride in the results

The town has focused on maintaining high quality fields on a limited budget. They are able to maintain a healthy soil ecosystem on 20 acres of natural grass with the use of soil testing, aeration, frequent mowing, and the use of organic fertilizer and soil amendments.

"Marblehead's twenty-year example of organic fields shows that success can be achieved in a variety of ways. It is an approach that focuses on healthy, biologically active soil combined with best management cultural practices and the exclusive use of natural, organic inputs. It is not measured in terms of 60 or 90 days, but rather over multiple years when results meet or exceed expectations. The goal here in Marblehead always has been playing fields that are free from harmful pesticides and meet community expectations."

- Chip Osborne, Chair, Marblehead Recreation and Parks Commission

Acknowledgements

Information for this case study was provided by Chip Osborne (Chair, Marblehead Recreation and Parks Commission) and Linda Rice Collins (Marblehead Recreation and Parks Commissioner). The case study was prepared by Rachel Massey and Lindsey Pollard (Toxics Use Reduction Institute). Funding for the preparation of this case study was provided by the Heinz Endowments.

TURI TOXICS USE REDUCTION INSTITUTE UMASS LOWELL

The Toxics Use Reduction Institute is a multi-disciplinary research, education, and policy center established by the Massachusetts Toxics Use Reduction Act of 1989. The Institute sponsors and conducts research, organizes education and training programs, and provides technical support to help Massachusetts companies and communities reduce the use of toxic chemicals.

Toxics Use Reduction Institute, University of Massachusetts Lowell • The Offices at Boott Mills West • 126 John Street, Suite 14 Lowell, MA 01852-1152 • (978) 934-3275 • www.turi.org

Subject: Re: Letter to the Conservation Commission
From: "Susan D. Chapnick, NEH" <s.chapnick@comcast.net>
Date: 12/6/2022, 3:44 PM
To: Jen Rothenberg <jenjenroth@gmail.com>
CC: Phil Lasker <phil_lasker@yahoo.com>, David Morgan <dmorgan@town.arlington.ma.us>, Joe Connelly <jconnelly@town.arlington.ma.us>

Jen,

I apologize. Neither I nor the Commission want you or the Park & Recreation Commission to feel uninvited to the conversation about artificial turf fields in wetland resource areas. I understand from your letter that you believe a conversation should have been initiated sooner, and I take it to heart that we need to improve communications.

As you may know, the Conservation Commission (ConCom) routinely proposes updates to our local regulations under the Town Bylaw. The last time we did this was in 2018. First, our process is internal to the Commission while we are generating a draft update of the regulations. We accomplish this by discussing internal drafts during multiple public meetings. Second, we distribute it to Town Counsel for input. After Town Counsel has edited & commented, we revise the draft and provide it to other boards and commissions. We then have a public meeting for discussion and vote on the Regulation updates.

The ConCom's December 15th meeting was scheduled in line with the process I outlined. We invited PRC to a discussion of artificial turf in jurisdictional areas as our first priority because ConCom believes that the meeting will afford us an opportunity for a broader discussion. This is an important topic that deserves attention from all stakeholders, especially your commission. If PRC thinks that this is not enough lead-time for appropriate input, we are open to postponing the discussion to a subsequent ConCom public meeting date. Our first few meetings in 2023 are: Jan 5th, Jan 19th, & Feb 2nd.

Thank you,
Susan

Susan D. Chapnick
Chair, Arlington Conservation Commission
s.chapnick@comcast.net

On 12/06/2022 1:44 PM Jen Rothenberg <jenjenroth@gmail.com> wrote:

Dear Ms. Chapnick:

The Conservation Commission members don't seem to have their emails listed on the town website making it difficult to connect with them directly. Could you please forward the attached letter to the entire commission?

Thank you,

Jen Rothenberg
On behalf of the Park & Recreation Commission

Athletic Playing Fields

Choosing Safer Options for Health and the Environment

TURI Report #2018-002
December 2018
(updated April 2019)

TURI
TOXICS USE REDUCTION INSTITUTE
UMASS LOWELL

Acknowledgments

This report was prepared by Rachel Massey, Joy Onasch and Lindsey Pollard (Toxics Use Reduction Institute), with input from: Elizabeth Harriman (Toxics Use Reduction Institute); Richard Clapp, David Kriebel, Polly Hoppin, and Molly Jacobs (Lowell Center for Sustainable Production); Rebekah Thomson (Field Fund); and Ken Geiser and Daniel Schmidt (University of Massachusetts Lowell). Testing of infill PAH content was conducted by Homero Harari (Icahn School of Medicine at Mount Sinai). Organic turf management information was provided by Chip Osborne (Osborne Organics) and Patrick Sullivan and Adam Anulewicz (Springfield Parks Department). Some of the information presented here has been previously posted on TURI's website at www.turi.org/artificialturf. Work on this report was supported by a grant from The Heinz Endowments. This report was updated in April 2019 to include new information on PAH testing.

Athletic Playing Fields: Choosing Safer Options for Health and the Environment

Introduction

Municipalities, universities, schools and other institutions frequently need to make decisions about maintenance and installation of athletic playing fields. This may include choosing between natural grass and artificial turf (also referred to as synthetic turf). Factors that may be considered include cost of installation and maintenance, number of days the field can be used, likelihood of player injuries, temperature of the playing environment, and athletes' exposure to chemicals.

A number of communities have requested technical assistance from TURI in evaluating the questions they face as they make these decisions. In response to these requests, TURI has conducted research on individual materials used in artificial turf. TURI has also worked with municipalities and other institutions to facilitate the adoption of athletic field management practices that are cost-effective and preferable for human health and the environment. This area of work has included projects to help communities eliminate or reduce the use of pesticides and facilitate the adoption of organic grass management practices.

This document provides information based on TURI's research on selected materials used in artificial turf. It also includes information on organic management of natural grass. TURI has identified organically managed natural grass as a safer alternative for sports surfaces. Additional educational documents and video resources are available on TURI's website.[1]

Principles of Toxics Use Reduction

TURI's work is based on the principles of toxics use reduction (TUR). The TUR approach focuses on identifying opportunities to reduce or eliminate the use of toxic chemicals as a means to protect human health and the environment. Projects to reduce the use of toxic chemicals often have additional benefits, such as lower life-cycle costs.

Children's Environmental Health

People of all ages benefit from a safe and healthy environment for work and play. However, special concerns exist for children. Children are uniquely vulnerable to the effects of toxic chemicals because their organ systems are developing rapidly and their detoxification mechanisms are immature. Children also breathe more air per unit of body weight than adults, and are likely to have more hand-to-mouth exposure to environmental contaminants than adults.[2] For these reasons, it is particularly important to make careful choices about children's exposures.

Artificial Turf Components

Artificial turf generally has several components, including a base layer made from gravel or stone; an artificial grass carpet, including a backing material and artificial grass fibers; and one or more infill materials, used to hold the grass fibers upright and provide cushioning, among other functions. Infill is the portion of the artificial turf that mimics the role of soil in a natural grass system. Many artificial turf fields also include a shock pad below the carpet for additional cushioning.[3] Depending on the infill type, this shock pad may be an optional component of the turf system, or may be required in order to provide a sufficiently resilient playing surface.

This document provides information on several infill materials. It is important to note that the materials available on the market may change frequently and the information presented here is not comprehensive. It is also important to understand that infill is just one component of an artificial turf system. This document focuses primarily on infill, but in evaluating the health and environmental impact of artificial turf, it is also important to consider the impacts of all the components, including the artificial grass blades, shock pad, and lower structural layers.

Regulatory/Testing Standards

There is no comprehensive regulatory or testing regimen specifically for artificial turf.

The standard cited most frequently by vendors is European Standard EN 71-3 – "Safety of Toys Part 3: Migration of certain elements" (the European Toy Safety Standard). For communities applying this standard, it is important to understand that it focuses only on metals. It does not cover other compounds that may be found in artificial turf materials, such as volatile organic compounds (VOCs), polyaromatic hydrocarbons (PAHs), phthalates, and others. The standard includes three different safety levels, so it is important to understand which level has been applied. Detailed information on this regulation is available in another TURI publication, *Chemicals in Artificial Turf Infill: Overview*.[4]

Other standards sometimes applied by researchers to artificial turf include regulatory standards for contamination of soil (e.g., comparing lead levels to those considered by the US EPA to pose a "soil-lead hazard" in play areas);[5] and checking metals in artificial turf runoff against federal and state regulatory levels for drinking water, surface waters and groundwater.[6] Studies in Europe have checked chemical levels in infill against a variety of regulatory standards for soil, sediment, and building materials, among other standards.[7] Germany has developed a regulation specifically for artificial turf, including requirements related to leaching of certain metals and organic compounds.[8]

Another relevant standard is California's Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65). This law requires disclosure of the presence of chemicals that are identified by the state of California as causing cancer or reproductive harm.

Artificial Turf: Chemicals in Infill

TURI has received many queries from communities and institutions that are working to understand the health and safety profiles of a variety of infill types. Therefore, TURI has reviewed existing literature on these infill types, with a focus on chemicals found in the materials. Additional detail on selected individual infills can be found on TURI's website.[9]

It is important to note that chemicals in infill are just one piece of the picture. The artificial grass blades pose concerns as well. Toxic chemicals such as lead are found in the artificial grass blades in some cases.[10] It is also important to understand and research the materials used in any pad or underlayment used in the layers below the infill.

Overview

Crumb rubber made from recycled tires, also referred to as **tire crumb** or as styrene butadiene rubber (SBR), is present in a large number of artificial turf fields.

A number of materials are currently marketed as alternatives to recycled tires. Some are based on synthetic materials, while others are mineral- or plant-based, or contain a mixture of natural and synthetic materials. Alternative synthetic infills include **ethylene propylene diene terpolymer (EPDM)**, **thermoplastic elastomer (TPE)**, and **waste athletic shoe materials**, among others. **Mineral-based** and **plant-derived** materials used in infill can include sand, zeolite, cork, coconut hulls, olive cores, and walnut shells, among other materials. Infill can also be made with acrylic-coated sand.

Some vendors may also offer an option of tire crumb coated with polyurethane. Limited information is available on the chemicals in the coating, the ability of the coating to reduce exposure to chemicals in the tire crumb, or the durability of the coating.[11]

Relatively little information is available on the chemicals present in, or emitted from, alternative infills. Some of them may pose less of a concern than tire crumb, but some may introduce serious hazards. Some available information on these materials is provided here, but there is a need for more research on all of these materials. Some of these materials have also been evaluated in a 2017 review by the Norwegian Environmental Agency[12] and in a 2018 review by the National Institute for Public Health and the Environment (RIVM) in the Netherlands.[13]

This overview is not comprehensive. New infills are introduced to the market frequently. It is important to understand that any synthetic material used as infill will pose some concerns related to introduction of rubber or plastic particles into the environment, as well as whatever specific chemicals may be found in the material. Mineral- and plant-based infills can pose hazards as well. In addition to any issues associated with infill, all artificial turf introduces synthetic materials into the environment through the other components, including breakdown over time of the artificial grass carpet.

Understanding rubber and plastic products: terminology

For those interested in understanding more about rubber and plastic products, the following terminology may be useful.

Thermosets vs. thermoplastics. Both natural and synthetic rubbers are **thermosets**. A key characteristic of a thermoset is that although heat is used in the initial manufacture of the material, once the material has been formed, it cannot be melted. For this reason, tires and other products made from thermosets cannot be melted and re-formed into new products. Among the materials used in artificial turf infills, SBR, EPDM and shoe sole materials are all thermosets.

Thermoplastics, in contrast, are materials that can be melted and re-formed into new shapes. Thermoplastic elastomers (TPEs) are one broad category within the larger category of thermoplastics.

Curing/crosslinking/vulcanization. Thermosets gain their stability through a process of **curing**, also referred to as crosslinking or vulcanization. Curing is a process of creating links among polymer strands in order to create a stable, three-dimensional structure. In the case of a thermoset, these links are composed of irreversible chemical bonds.

A variety of chemicals can be used in the curing process. These include chemicals that become part of the crosslinking bond, as well as chemicals that catalyze or accelerate the crosslinking process. The term "vulcanization" is often used specifically to refer to crosslinking with sulfur.

In contrast to the large molecules of a polymer, the molecules added in the curing process are often relatively small. Some of these molecules may remain present as free molecules in the final material, and these may be released during product use.

Plasticizers. Plasticizers are added to stiff or rigid materials to make them more pliable. One important category of plasticizers is the phthalate esters, also commonly referred to simply as phthalates. Mineral oil can also be used as a plasticizer. The specific plasticizers used in a given product are frequently not disclosed.

Other additives. A variety of other additives may be used in rubber and plastic products. **Fillers** such as carbon black or silica can be used to attain specific material properties or simply to extend the volume of the material. **Stabilizers** can be added to decrease the effect of light, heat or other environmental conditions on the material. Other additives that may be used include **pigments** and **antimicrobial agents**.

Tire crumb

A large number of chemicals are found in tire crumb. Many of these have adverse effects on human health or the environment. In a literature review, the US Environmental Protection Agency (EPA) identified just over 350 chemicals or chemical categories that were discussed in existing literature on tire crumb.[14] The presence and amount of a given chemical can vary depending on the sample of tire crumb.

Table 1 shows the categories of chemicals considered by EPA, with examples of individual chemicals in each category.[15] As shown in the table, these include metals, such as lead and zinc; volatile organic compounds (VOCs); semi-volatile organic compounds (SVOCs); and a variety of uncategorized chemicals including vulcanization compounds (chemicals used in rubber curing). The broad category of SVOCs includes PAHs, phthalate esters, and chemicals that may be applied to the crumb rubber as biocides during the life of the artificial turf.

Some of the chemicals found in tire crumb are endocrine disrupters (e.g., phthalate esters); some are known or suspected carcinogens (e.g., arsenic, cadmium, benzene, styrene); and some are associated with other human health effects.[16] A recent study evaluated the potential carcinogenicity of 306 chemicals found in tire crumb and found that 197 of them met certain carcinogenicity criteria, while 58 were actually listed as carcinogens by a government agency.[17]

Table 1: Selected categories of chemicals found in tire crumb

Category[a]	Subcategory	Examples
Metals		Aluminum, arsenic, barium, cadmium, chromium, copper, lead, nickel, zinc
VOCs		Benzene, benzothiazole, hexane, naphthalene, styrene, toluene, xylenes
SVOCs	PAHs	Anthracene, benz(a)anthracene, fluoranthene, naphthalene, phenanthrene, pyrene
	Phthalate esters	Benzylbutyl phthalate, di(2-ethylhexyl)phthalate [a.k.a. bis(2-ethylhexyl)phthalate]
	Biocide product ingredients	May include quaternary ammonium compounds such as alkylbenzyldimethyl ammonium chloride, alcohol ethoxylate 6, or others[b]
Other[c]		4-tert-(octyl)-phenol [a.k.a. 4-t-octylphenol], butylated hydroxytoluene

Sources:
Thomas K, Irvin-Barnwell E, Giuseppi-Elie A, Ragin-Wilson A. August 2016. *Research Protocol: Collections Related to Synthetic Turf Fields with Crumb Rubber Infill.* US EPA, CDC and ATSDR. Accessed at https://www.epa.gov/sites/production/files/2016-08/documents/tcrs_research_protocol_final_08-05-2016.pdf, January 2, 2017.
US EPA. December 2016. *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds: Status Report.* EPA/600/R-16/364. Accessed at https://www.epa.gov/chemical-research/december-2016-status-report-federal-research-action-plan-recycled-tire-crumb, March 21, 2017.
[a] Note: Categorization shown here follows categories used in EPA's August 2016 publication.
[b] Thomas et al. note these have been identified by the California Office of Environmental Health Hazard Assessment (OEHHA) as "potential turf biocides."
[c] As organized by Thomas et al., this category includes "potential rubber curatives, antioxidants/antiozonants, and other chemicals reported in literature."

Exposure to low doses of multiple chemicals can have health effects that may not be predicted based on the expected effects of each exposure individually. For this reason, some studies have considered the mix of chemicals in tire crumb, rather than looking at each individually. A study of a tire shredding facility in Taiwan tested airborne particulates from the facility for mutagenicity, and found that they showed "a substantial presence" of mutagens.[18] Another study considered the mutagenicity of dust and fumes at two tire-shredding facilities; they found "high mutagenic activity" of dust and fumes at one facility and "almost no mutagenic activity" at the other, a difference they attributed both to choices of chemicals and to the way in which each facility operated.[19]

EPDM

EPDM rubber is a specialty elastomer that can be mixed with high levels of additives and oils while retaining its desirable physical properties, including strength and resistance to tearing. Additives can include oil, carbon black, and other materials. EPDM may be manufactured with anywhere from 15 to 100 parts of oil per 100 parts of polymer.[20] Like tire crumb, EPDM is a vulcanized (cured) rubber product, so it can be expected to contain vulcanization compounds. Not all EPDM infills are necessarily the same, so it is important to find out what chemicals are present in any given EPDM product.

There has been limited examination of EPDM granules to evaluate their suitability from a public

health and environmental perspective. In one study published in 2004, the Norwegian Building Institute (NBI) examined levels of selected chemicals in one sample of EPDM infill, comparing these levels with those found in three samples of recycled tires. The study found that the EPDM rubber contained more chromium than the tire material, similar amounts of zinc, and lower concentrations of PAHs, phthalate esters, and phenols. Polychlorinated biphenyls (PCBs), which were found in one sample of recycled rubber, were not found in the EPDM. The authors state that "with the exception of chromium and zinc, the EPDM rubber contains lower concentrations of hazardous substances than the recycled rubber types overall."[21] A 2008 study by the Danish Ministry of the Environment also included tests of one sample of EPDM.[22] A study supported in part by the tire industry in France found that EPDM emitted larger amounts of VOCs than tire crumb.[23]

In reviewing pros and cons of EPDM infill, the Norwegian Environmental Agency notes possible concerns about VOC emissions at indoor fields, introduction of microplastics into the environment, and aquatic toxicity from leachate, among other factors.[24]

RIVM reviewed the limited existing literature on EPDM infill as well as conducting limited testing of its own. RIVM concludes that EPDM infill is likely to contain PAHs but at lower levels than tire crumb; carbon black may be a concern in black EPDM, but not in EPDM of other colors; and phthalate esters such as diethylhexyl phthalate (DEHP), an endocrine disrupter, may be present in the material. Nonyl- and octylphenols, also endocrine disrupters, are detected at low levels in both EPDM and tire crumb. RIVM also notes that leaching of zinc from EPDM could potentially pose a concern similar to the level of concern posed by tire crumb.[25]

In summary, EPDM may pose some of the same health and environmental concerns posed by tire crumb, although it may contain lower levels of some important categories of chemicals of concern and a smaller number of chemicals of concern, compared with tire crumb. Additional detail on EPDM infill is available on TURI's website.[26]

TPE

Thermoplastic elastomer[27] (TPE) is a general term that can encompass a variety of materials. TPEs are composed of two materials: one that is hard at room temperature and one that is soft and rubbery at room temperature. The two materials can be either chemically bonded or blended together.

TPEs generally do not require curing or vulcanization during manufacturing. However, some products marketed as TPE do contain a vulcanized material as one part of the mix, further complicating the distinctions among material types.

As with EPDM infill, TPE infill has not been studied extensively. Based on the limited information available on TPE used in artificial turf infill materials, it appears to contain lower levels of many toxic chemicals than tire crumb. In particular, measurements indicate that TPE infill emits fewer VOCs. Furthermore, since TPE does not require vulcanization (curing), it is generally expected to be free of the vulcanizing agents that are used in crumb rubber made from tires.[28] However, TPE infill can contain and emit some chemicals of concern, and since individual TPE products may vary widely, it is important to obtain information on the chemicals found in any individual product that is under consideration.

Although the term TPE encompasses a broad category of materials, TURI examined details about one TPE infill to better understand the chemical composition. Using information obtained from Safety Data Sheets and the US National Library of Medicine's database (ChemID*plus)*, the TPE sample was found to be composed of styrene block copolymer, polyethylene, paraffin oil, calcium carbonate (chalk), carbon black, and unspecified stabilizers/antioxidants. Carbon black is identified

by the International Agency for Research on Cancer as a possible human carcinogen (Group 2B), and many forms contain a variety of adsorbed compounds, including PAHs.[29]

A 2006 study by the Norwegian Pollution Control Authority compared three indoor fields: two containing crumb rubber (SBR) infill made from tires, and one containing TPE infill.[30] In measurements of airborne dust, the quantity of fine particulate matter ($PM_{2.5}$) was elevated for the two SBR fields, while quantities were in the expected ranges for an indoor setting for the TPE field. The researchers also noted that the dust generated by the TPE field was free of the vulcanization compounds, preservative compounds, and carbon black found in the SBR fields. Dust from all locations contained PAHs, but the levels in the dust generated by the TPE field were lower than those in the SBR dust. Total VOCs measured at the TPE field were also lower than those measured at the tire crumb fields. Phthalate esters were present at comparable levels at all locations; phthalate esters measured in airborne dust during one time period were slightly lower at the TPE field, but were higher at the TPE field during another time period.

RIVM's literature review suggests that little information is available on TPE infills, but that they are likely to contain lower levels of metals and VOCs than tire crumb or EPDM, lower or comparable levels of PAHs, and comparable levels of phthalate esters.[31]

In summary, based on the limited information that is available, TPE infill is likely to contain fewer chemicals of concern than tire crumb, but is still likely to contain some chemicals of concern. Communities considering purchasing a TPE infill product may wish to request additional information from the vendor on the specific type of TPE used. Additional detail on TPE infill is available on TURI's website.[32]

Waste shoe material

Infill made from post industrial waste shoe material can be made from a single brand of shoe product, or from several mixed together. For example, the Sole Revolution brand of infill may draw materials from a variety of shoe manufacturers, while Nike Grind is made from Nike® shoe material.[33]

Shoe manufacturing uses a wide variety of materials, and manufacturers' choices about these materials vary over time. Factors relevant to the environmental, health and safety characteristics of athletic shoe materials include the polymers used in shoe soles, the additives that impart key performance characteristics to those polymers, and the mandatory and voluntary testing protocols used to limit toxics in shoe materials.

Some shoe materials are governed by Restricted Substances Lists (RSLs) developed by shoe manufacturers to minimize or eliminate the use of certain chemicals that pose particularly high concerns. For example, Nike has an RSL that "restricts approximately 350 substances that have been regulated or voluntarily phased out of [their] manufacturing processes,"[34] and Nike Grind materials are governed by the RSL.[35]

According to Nike's RSL, certain VOCs (such as benzene or toluene) are subject to tight control in the manufacturing process. Thus, these substances are not necessarily absent from Nike products but they are used in the minimum quantity possible to achieve the desired effect. Nike also limits the levels of other categories of chemicals of concern, such as specific PAHs and specific phthalate esters.[36]

Waste shoe material can contain some of the same chemicals of concern as other rubber infills, although it offers the advantage that levels of some of the chemicals of highest concern may be regulated by an RSL. Neither of the recent assessments by European government agencies considered waste shoe material in detail as an

alternative to tire crumb. TURI has not identified detailed independent studies of waste shoe material as used in infill.

Acrylic-coated sand

TURI was able to gather information on one acrylic-coated sand product that is currently marketed for use in artificial turf.[37] According to the manufacturer, this product is composed of well-rounded sand, a proprietary (undisclosed) acrylic, a Microban® antimicrobial, and a pigment.[38]

The specific acrylic used in the product is a proprietary component of the manufacturer's production process, so no other information was available on its health and environmental properties. According to the manufacturer, it does not contain any additives beyond the pigment and antimicrobial.[39] Laboratory test results provided by the manufacturer show that all PAHs for which tests were conducted were below the detection limit.[40] The manufacturer also states that the product was below the detection limit for all VOCs for which tests were conducted.[41]

The antimicrobial helps to protect the acrylic coating from deterioration. The company currently uses ZPTech®, a zinc-based antimicrobial. According to the Microban website, "ZPTech is a broad-spectrum antimicrobial."[42] According to Microban, the product "encapsulates zinc pyrithione in customized carriers." Zinc is released when the material is exposed to water.[43] The product is also available without the antimicrobial.

According to the manufacturer, the antimicrobial product originally used in the product was triclosan, but the transition to the zinc-based antimicrobial has been complete since the end of 2016.[44] Triclosan poses concerns based on bioaccumulation and adverse health and environmental effects.[45]

Test data are available both for presence of metals in the material and for leaching of metals from the material. The metal that appears in the largest quantity is zinc (18 and 57 mg/kg in two samples respectively). Tests show that the material leaches 0.82 mg/L of iron and 0.13 mg/L of zinc.[46]

Many of the categories of organic chemicals of concern that are present in the other synthetic infills may be lower, or absent, in acrylic-coated sand. On the other hand, there may be a need for more research on the environmental implications of the broad use of sand coated with an antimicrobial-infused polymer.

Mineral- or plant-based materials

A growing list of mineral- or plant-based materials is marketed for use in infill. At least one of these options, zeolite, poses serious health concerns. The other materials have generally not been studied in depth. As with the other materials discussed in this report, it is essential to gather detailed information on these materials to understand their potential health or environmental impacts. This section mentions a few areas of concern, but is not comprehensive.

Zeolite. Zeolite poses a respiratory hazard. Animal studies suggest that exposure to some types of zeolites may be associated with increased risk of developing mesothelioma.[47] Erionite, one type of zeolite, poses particular concerns; its health effects can be similar to those of asbestos.[48]

Cork. Respiratory disease has been documented in cork workers exposed to cork dust. For example, a 1973 study concluded that workers in the cork industry may suffer from various complaints related to the inhalation of cork dust. It states that "workers in factories where cork is processed and transformed into commercial products may acquire incapacitating disease of the respiratory tract."[49] Respiratory disease associated with cork dust exposure is known as suberosis. Fungi that frequently colonize cork appear to play some role in the disease, although the disease is not fully understood.[50]

Coconut fiber. Some individuals are allergic to coconut, although coconut allergies are relatively rare. The American College of Allergy, Asthma & Immunology notes that "coconut is not a botanical nut; it is classified as a fruit, even though the Food and Drug Administration recognizes coconut as a tree nut. While allergic reactions to coconut have been documented, most people who are allergic to tree nuts can safely eat coconut."[51]

Walnut shells. Nut shells may pose concerns related to allergies if nut allergens are present on the shells. Walnut shells are used as an alternative to silica in sand blasting, and there is one report of an individual developing an allergic reaction in that context.[52] According to the manufacturer, USGreentech, the shells used in Safeshell[53] (a proprietary infill made from walnut shells) are processed to remove allergens to "below 2.5 parts per million."[54]

Fibers. A variety of respirable plant-based fibers can cause disease and disability. For example, cotton dust is a well-known source of respiratory disease.[55] TURI has not identified any studies that consider possible hazards related to plant-based fibers in infill.

Comparing infills

As noted above, infills are just one part of an artificial turf system and all portions of the system should be evaluated as part of the decision making process. Table 2 provides comparative information on selected chemicals or chemical categories in infill materials.

Most infill vendors are able to provide test results for a number of metals. The information on metals in this table is drawn primarily from one set of tests on individual infill products provided by a vendor of multiple infill types. The table shows specific information on lead because it is a particular concern for children's health, and zinc because it has been flagged as a possible environmental concern associated with artificial turf. However, other metals may be equally or more important. Communities working to make a decision should request the most up-to-date results on metals present in the specific product they are considering.

Information on other chemicals may not be as readily available from vendors. Communities may wish to request information on organic chemicals, such as VOCs or PAHs, found in any specific product. Note that the term "organic" in this context refers to any chemical that is based on carbon. This is not the same as the use of "organic" to describe pesticide-free management of natural grass systems.

As shown in the table, vulcanization compounds are likely to be found in tire crumb, EPDM, and shoe materials. VOCs have been measured in many of the materials, but are higher in some than in others. Similarly, PAHs may be present in varying quantities depending on the material. There may be some increased predictability when purchasing waste shoe materials if they are subject to an RSL. Mineral- and plant-based materials are unlikely to pose concerns related to the four broad categories of synthetic chemicals listed in the table, but some pose other significant concerns. It is important to note that even in cases where the chemicals listed below may be absent, infills may pose other hazards.

In the course of TURI's research, a number of data gaps were identified. For example, not all vendors were able to provide information on PAHs in infill products. To help address this data gap and better understand the presence of PAHs in these materials, TURI contracted with the Icahn School of Medicine at Mount Sinai to conduct limited testing on samples of commercial infill products. As shown in Table 2, the tire crumb sample contained the largest total PAH concentration, with over 500 mg/kg. Waste athletic shoe material and EPDM had the next largest total PAH concentrations, although they were both an order of magnitude lower than tire crumb (55 and 20 mg/kg respectively).[56]

Table 2: Comparing infills: Selected categories of chemicals of concern

Category	Tire crumb	EPDM	Shoe materials[a]	TPE	Acrylic-coated sand	Mineral- or plant-based
Lead[b]	Present	Present	Present	Present	Below detection limit[c]	Absent in some cases
Zinc[b]	Present	Present	Present	Present	Present[c]	Present in some cases
Other metals[b]	Present	Present	Present	Present	One additional metal present[c]	Present
Vulcanization compounds[d]	Present	Present	Present	Generally absent	Expected to be absent	Zeolite, when present, poses serious respiratory hazard. Plant-based materials can pose concerns related to dust, fungi, or allergens. Vulcanization compounds and phthalates are expected to be absent; VOCs and PAHs are expected to be low or absent.[h]
Phthalates	Present[e]	Present (lower)[f]	May be present, but subject to RSL	Present[g]	Expected to be absent	
VOCs	Present[e]	Present (lower in some cases, higher in others)[f]	Expected to be present, but subject to RSL	Present (lower)[g]	Expected to be absent	
PAHs	Present[e]	Present (lower)[f]	May be present, but subject to RSL	Present (lower)[g]	Below detection limit[c]	
PAHs (TURI sample)[i]	Present (highest) (548 mg/kg)	Present (20 mg/kg)	Present (55 mg/kg)	Present (below 10 mg/kg)		

[a] Some information in this column is drawn from Nike's RSL. *VOCs:* Nike's RSL restricts benzene to 5 ppm and a number of other VOCs to a total of 1,000 ppm. *PAHs:* Nike's RSL restricts certain PAHs to 1 ppm each and sets a 10 ppm total for all PAHs on the list. *Phthalate esters:* Certain phthalate esters are listed on the Restricted Substances Lists (RSLs) of major shoe manufacturers. Specifically, Nike restricts all ortho-phthalates to a total of 1,000 ppm.

[b] Except where otherwise noted, information is drawn from Labosport. 2014. *Technical Report: Toxicological Analysis of Performance Infill for Synthetic Turf Fields according to EN 71-3 Standard – Safety of Toys Part 3: Migration of Certain Elements.* Report #R14565CAN-A1, provided to Jason Smollett, FieldTurf.®

[c] AIRL, Inc. 2018. Lab report #304074, provided to Ross Vocke, US Greentech. Detection limit 10 µg/Kg for PAHs, 0.25mg/Kg for metals.

[d] By definition, the vulcanized rubber products (tire crumb, EPDM and shoe materials) may contain residual vulcanization compounds. TPE is not vulcanized; however, in some cases, products marketed as TPE are a blend that also contains vulcanized rubber.

[e] US EPA. 2016. *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds: Status Report.* EPA/600/R-16/364. Viewed on October 23, 2018, at https://www.epa.gov/sites/production/files/2016-12/documents/federal_research_action_plan_on_recycled_tire_crumb_used_on_playing_fields_and_playgrounds_status_report.pdf.

[f] Norwegian Building Research Institute (NBI - BYGGFORSK). 2004. "Potential Health and Environmental Effects Linked to Artificial Turf Systems: Final Report." Report prepared for the Norwegian Football Association. Project no. 0-10820. September 10, 2004. Authors: Thale S.W. Plesser, Ole J. Lund. Moretto R. 2007. *Environmental and health assessment of the use of elastomer granules (virgin and from used tires) as filling in third-generation artificial turf.* Report prepared for ADEME/ALIAPUR/Fieldturf Tarkett. Note: The terms "lower" and "higher" refer to the comparison with tire crumb.

[g] Dye, Christian, A. Bjerke, N. Schmidbauer, S. Manø. 2006. *Measurement of Air Pollution in Indoor Artificial Turf Halls.* Trondheim, Norway: Norwegian Pollution Control Authority/Norwegian Institute for Air Research. Report #NILU OR 03/2006. TA number: TA-2148/2006. ISBN number 82-425-1716-9. Note that in this study, phthalates measured in airborne dust at a TPE field were found to be lower at one time, and higher at another time, compared with levels measured at a tire crumb field.

[h] Plants can produce some substances that are classified as VOCs. However, based on currently available information, the plant-based materials used in infill are not expected to pose concerns related to VOCs. PAHs can be taken up by plants from ambient pollution in some cases.

[i] Toxics Use Reduction Institute. 2019. "Artificial Turf Infill: Laboratory Testing Results: PAHs." Fact sheet available at www.turi.org/Our_Work/Community/Artificial_Turf/PAH_Test_Results. TURI contracted with the Icahn School of Medicine at Mount Sinai to conduct limited testing to supplement information available in existing literature.

When researching turf options, communities should evaluate materials carefully and may wish to require additional testing to ensure they have considered the full range of chemicals. Existing tests generally apply only to the sample on which they were conducted, so it is important to obtain data on the specific product in question.

Environmental Concerns

Environmental concerns include loss of wildlife habitat and contaminated runoff into the environment. A study by the Connecticut Department of Environmental Protection identified concerns related to a number of chemicals in stormwater runoff from artificial turf fields. These include both metals and organic compounds. They noted high zinc concentrations in stormwater as a particular concern for aquatic organisms. They also noted the potential for leaching of high levels of copper, cadmium, barium, manganese and lead in some cases. The top concerns identified in the study were toxicity to aquatic life from zinc and from whole effluent toxicity (WET).[57] WET is a methodology for assessing the aquatic toxicity effects of an effluent stream as a whole.[58] In another example, a study found that leachate from several artificial turf systems was toxic to aquatic organisms.[59]

Another environmental concern is migration of synthetic particles into the surrounding environment. Both infill particles and broken synthetic grass fibers do not stay limited to the boundaries of the artificial turf field. Photographic evidence collected by community members in Massachusetts show broken pieces of artificial grass fibers widely dispersed in environments surrounding artificial turf fields. Field maintenance protocols provide for periodic addition of infill to replace infill lost from the field in the course of play, further demonstrating that not all infill particles remain in place within the field. With growing concern about global microplastic pollution, some communities are working actively to reduce the amount of plastic they introduce into the environment. Little or no research has been conducted on ways in which dust and broken particles from artificial turf fields may contribute to microplastic pollution in the environment.

Acrylic-coated sand particles, according to the manufacturer, pose less risk of migrating into waterways compared with other infills because they do not float; however, they could still generate dust that may move offsite. To the extent that particles migrate off the original field site and enter water resources, there could be concerns about whether sedimentary organisms could incorporate these materials and whether they could enter the food chain in this way.

Disposal of the synthetic materials, including the infill and the shock pad, poses an additional concern. Some synthetic materials may be reusable one or more times, while others may have to be disposed of in a landfill or through incineration when the field is due for replacement. RIVM notes that it may be possible to use waste material from a replaced artificial turf field in some other sporting applications, but also notes that due to the degradation of the material over time, this will not always be possible. RIVM

also notes that the substructure elements of an artificial turf field may need to be cleaned prior to recycling, if they are contaminated with any chemicals that have leached from infill. For the limited set of infills it analyzes, RIVM assumes an average 10 year service life for artificial turf fields and assumes that the infill materials are not reused on additional fields.[60]

Artificial Turf and Heat Stress

In sunny, warm weather, artificial turf can become much hotter than natural grass, raising concerns related to heat stress for athletes playing on the fields.[61] Research indicates that all artificial turf reaches higher temperatures than natural grass,[62] although some infill materials may reach higher temperatures than others.

A report by the New York State Department of Environmental Conservation found that surface temperatures on an artificial turf field were 35°F to 42°F higher than those on natural grass.[63]

Another study found that the highest temperature measured on artificial turf was 60.3°F greater than that observed on natural grass.[64]

In another study, artificial turf fibers reached temperatures of 156°F under direct sunlight, while the crumb rubber infill reached 101°F.[65]

Measurements taken by sports managers at Brigham Young University found that the surface temperature of artificial turf was 37°F higher than asphalt and 86.5°F hotter than natural turf. The hottest surface temperature recorded during the study was 200°F on a 98°F day. Even in October, the surface temperature reached 112.4°F.[66]

Irrigation can lower field temperature for a short time. A study by Penn State's Center for Sports Surface Research found that frequent, heavy irrigation reduces temperatures on artificial turf, but temperatures rebound quickly under sunny conditions.[67] Another study found that irrigation could lower temperatures by 10 to 20 degrees for a period of at least 20 minutes.[68] Another found that irrigation lowered the surface temperature from 174°F to 85°F; however, the temperature rebounded to 164°F after 20 minutes.[69]

Heat-related illness can be a life-threatening emergency. Experts note that athletic coaches and other staff need to be educated about heat-related illness and understand how to prevent it, including cancelling sport activities when appropriate.[70] In one example, a number of students developed heat-related illness after band practice on a new artificial turf field.[71]

Heat can also affect chemical emissions. For example, one study expressed concern about PAH emissions from tire crumb at elevated temperatures.[72]

Additional information on heat is available in TURI's website.[73]

Injuries

Injury rates can be affected by a variety of factors, including the type and condition of the playing surface as well as equipment used and type and level of sport. Studies show variable outcomes in the rates and types of injuries experienced by athletes playing on natural and on artificial turf.[74]

One particular concern is increased rates of turf burns (skin abrasions) associated with playing on artificial turf. For example, a study by the California Office of Environmental Health Hazard Assessment found a two- to three-fold increase in skin abrasions per player hour on artificial turf compared with natural grass turf.[75] These study authors noted that these abrasions are a risk factor for serious bacterial infections, although they did not assess rates of these infections among the players they studied.

Additional information on injuries is available in TURI's website.[76]

Current Federal and State Studies on Artificial Turf and Tire Crumb

As noted above, a number of existing studies have examined the chemicals present in artificial turf, with a particular focus on tire crumb. Some of these studies include a risk assessment, in which an effort is made to estimate the number of cases of disease that could result from exposure to a subset of the chemicals found in tire crumb.

After reviewing the studies, federal and state officials have identified a need for additional information. Two current studies are described here.

California Office of Environmental Health Hazard Assessment

In 2015, the California Office of Environmental Health Hazard Assessment (OEHHA), an office within the California Environmental Protection Agency, began a new study of the potential health effects of exposure to artificial turf as well as playground mats made from recycled waste tires. The study includes analyses of samples of new and used artificial turf and playground mats; the development of exposure scenarios; and the development of a risk assessment based on this information. OEHHA has sampled more than 30 fields in a range of climate regions within California, including both new and old fields.[77] OEHHA is also examining the range of routes by which players and bystanders can be exposed to chemicals found in the artificial turf materials, including through skin contact, breathing, and ingestion. As part of this effort, OEHHA has conducted a survey of both child and adult athletes to learn more about whether they report getting infill materials on their skin, in their eyes, and/or in their mouths during the course of play.[78]

In the future, OEHHA may also examine people's actual exposures through measurement of biological specimens or use of personal monitors.[79]

Research by federal agencies

Three federal agencies are also engaged in an assessment of potential health effects of exposure to artificial turf. The agencies working on the study

are the US EPA, the Consumer Product Safety Commission (CPSC), and the Agency for Toxic Substances and Disease Registry (ATSDR) within the Centers for Disease Control. As background on the need for this study, EPA noted that "limited studies have not shown an elevated health risk from playing on fields with tire crumb, but the existing studies do not comprehensively evaluate the concerns about health risks from exposure to tire crumb."[80] EPA further states, "While this effort won't provide all the answers about whether synthetic turf fields are safe, it represents the first time that such a large study is being conducted across the U.S."[81]

In this project, the federal agencies are working to identify chemicals of concern found in tire crumb, and gain a better understanding of how people are exposed to tire crumb on playing fields and in playgrounds. The study has four components: a literature review and analysis of gaps in current knowledge; a tire crumb characterization study; a sports turf exposure characterization study; and a playground study.[82]

The agencies have issued summary documents based on the work they completed in 2016, including a summary of all the literature that was reviewed and a detailed spreadsheet showing information on which chemicals were examined in each study.[83] These are useful resources for people interested in learning more about the studies that have been conducted to date.

Among other information, the federal agencies' preliminary report on their work provides an overview of knowledge gaps about tire crumb used in playing surfaces. For example, with regard to characterizing tire crumb materials, there are gaps related to chemical characterization, emissions assessments, microbial assessments, bioaccessibility, and variability.[84] For example, EPA notes that there is a lack of studies that measure a wide range of tire crumb samples and consider the full range of chemicals that can be found in tires. Regarding emissions, EPA notes that "few laboratory-based studies have investigated VOC and SVOC emissions from synthetic fields and playgrounds under different temperature conditions," and those studies that do exist have considered only a limited set of chemical emissions. Regarding bioaccessibility (the likelihood that the human body will take up the chemicals present in the material), there is a lack of studies that "systematically measure a wider range of metal and organic chemical constituents, using multiple simulated biological fluids, and across a large range of tire crumb rubber samples." Finally, EPA notes that "most studies characterizing tire crumb rubber from synthetic fields and playgrounds in the United States have been relatively small, and restricted to a few fields or playgrounds. Measurements for samples collected from a wider range of tire recycling plants, synthetic fields, and playgrounds across the United States is lacking."

Additional gaps exist with regard to other important areas of study. For example, with regard to characterizing exposure and risk, there are gaps related to exposure factors, dermal or ingestion exposures, exposure through broken skin or through eyes, and more. EPA notes that while a number of studies have examined possible exposures through inhalation, "more limited information is available for understanding dermal and ingestion exposures." EPA also notes that "little information is available on the potential for increased exposures via broken skin (i.e., due to cuts and scrapes) and through ocular fluids," and that few studies have examined the potential cumulative effects of exposures through multiple routes, including inhalation, ingestion, and skin exposure.

Other parts of the federal agencies' work are still in progress at the time of publication of this report. EPA and CDC/ATSDR have completed the collection and analysis of samples for the exposure and tire crumb characterization parts of the study, and the draft report is now undergoing technical peer

review, according to EPA's website, updated September 2018.

In addition, CPSC has completed a study of how children interact with recycled tire materials on playgrounds. CPSC used a combination of focus groups, field observations, and a national survey of parents and child-care providers to collect information on children's behavior when playing on playground surfacing made from recycled tires or other materials. CPSC focused in particular on the behavior and experience of toddlers on playgrounds. Among other findings, CPSC noted that children "may be commonly exposed to rubber surfacing materials in various ways, such as chewing the materials and being scraped by them." They noted concerns including children mouthing and chewing rubber surfacing materials; stains from rubber surfacing left on children's skin and clothing; children picking up rubber mulch; children being exposed through bare feet; and children eating snacks at playgrounds. The CPSC found that the study findings raise concerns that deserve further investigation.[85]

What is a Risk Assessment?

Many existing studies on the use of tire crumb in artificial turf are quantitative risk assessments. Risk assessment is a methodology used by researchers to estimate the number of cases of disease that could result from anticipated exposure. To develop a risk assessment, researchers may bring together information on chemical toxicity, level of exposure, route of exposure, expected ages at which exposure may occur, expected duration of exposure, and expected ways in which the body may absorb and process the chemicals. Since risk assessments often consider just a subset of the chemicals present in artificial turf, they may not present a complete picture. In addition, a number of assumptions have to be made in the course of the assessment, and the final result is an estimated number of cases of disease (e.g., an expected number of cancer cases per million people exposed). This number may be used in discussions about levels of risk that are considered acceptable.

The Toxics Use Reduction approach does not rely on quantitative risk assessments; rather, the focus is on reducing or eliminating toxic chemical use when possible.

New Regulatory Initiatives in Europe

The European Union regulates chemicals under its Registration, Evaluation and Authorisation of Chemicals (REACH) regulation. The Netherlands has developed a proposal under REACH to regulate the presence of PAHs in sports turf infills.[86] Specifically, the proposal would limit the level of eight PAHs in sports turf infills, as well as in materials used in loose form on playgrounds. The proposed restriction is based on a finding that the EU's current exposure limits for these materials are not sufficiently protective. The proposed restriction would limit the sum of the eight PAHs to 17 mg/kg in granules or mulches used as infill or as playground surfacing in order to reduce the estimated cancer risk for exposed individuals to 2.6×10^{-6} (2.6 per million).[87] The proposed restriction was developed in response to concerns about PAHs in waste tires but would apply to any alternative material as well. This is the first step in a multi-stage regulatory and consultation process. If there is agreement on the restriction, the estimated timeline is that it would be adopted in 2020.[88]

Laboratory Testing of Artificial Turf

A number of communities have asked TURI what types of information they should gather as they make decisions about artificial turf fields. All the issues noted above are relevant for decision making, but confusion often arises around the testing that may be conducted on turf infill and grass blades.

In general, manufacturers are able to provide test data covering a number of metals of concern. Manufacturers often provide a comparison between this information and the standards provided in the European Toy Safety Standard. Communities may choose to order their own tests on metal contents as well.

Less information tends to be available on other, non-metal chemicals that may be present in either the infill or the grass blades. Therefore, communities may wish to either conduct their own testing or request test results from the vendor on these other chemicals. For example, it may be useful to ask the vendor for data on VOCs, SVOCs, and PAHs present in the product.

Safer Alternative: Natural Grass

Natural grass fields can be the safest option for recreational space, by eliminating many of the concerns noted above. Grass fields may be maintained organically or with conventional or integrated pest management (IPM) practices. Organic turf management eliminates the use of toxic insecticides, herbicides and fungicides.

Photo credit: Adam Anulewicz

Forest Park, Springfield, MA, 2018.

Natural grass can reduce a field's overall carbon footprint by capturing carbon dioxide. A natural grass field can also provide a number of ecosystem services, such as providing habitat for invertebrates and microorganisms, reducing the heat island effect in urban areas, and helping to control flooding, among others.

Table 3 shows a broad comparison between artificial turf and natural grass, including conventionally and organically managed grass. As shown in the table, artificial turf can pose chemical hazards related to chemicals either present in the surfacing material or applied to the surface. Cleaners, disinfectants and even herbicides may sometimes be applied to the artificial turf surface as well. Natural grass, on the other hand, only contains whatever is already in the ambient environment and generally does not include polymers, rubber and plastic additives, or respiratory hazards such as zeolite. Conventionally managed natural grass may be treated with synthetic pesticides or fertilizers; organically managed natural grass builds soil health, making it unnecessary to apply chemical treatments.

Table 3: Comparing artificial turf with natural grass				
Category	**Subcategory**	**Artificial turf**	**Natural grass – conventional**	**Natural grass – organic**
Chemicals	**Present in surface**	Polymers, additives; respiratory hazards, e.g., zeolite	Ambient environmental exposures only	
	Applied to surface	Cleaners, disinfectants, herbicides	Synthetic pesticides, fertilizers	Soil health built through aeration, proper mowing practices, organic soil amendments, and other approaches
Other health hazards	**Heat**	Higher	Lower	
	Risk of skin abrasions and infections	Higher	Lower	
	Other injuries	Variable injury patterns		
Other environmental considerations	**Ecosystem services**	None	Habitat for a range of organisms; carbon fixation; water/flood control; reduction of heat island effect in urban areas	
	Migration of materials	Particles of infill & artificial grass blades can migrate into environment	Possible fertilizer runoff or pesticide drift	n/a
	Water use	Irrigation may be used to lower temperature	Irrigation may be used to support grass growth	Irrigation may be used to support grass growth; organic management reduces irrigation needs by supporting root development

Organic Management of Recreational Field Space

Organic management of a recreational field space requires a site-specific plan to optimize soil health and minimize long-term costs. Over time, a well-maintained organic field is more robust for recreational use due to a stronger root system than that found in a conventionally managed grass field. Water needs also decrease over time. Key elements of organic management include the following steps.[89]

- **Field construction**: Construct field with appropriate drainage, layering, grass type, and other conditions to support healthy turf growth. Healthy, vigorously growing grass is better able to outcompete weed pressures, and healthy soil biomass helps to prevent many insect and disease issues.

- **Soil maintenance**: Add soil amendments as necessary to achieve the appropriate chemistry, texture and nutrients to support healthy turf growth. Elements include organic fertilizers, soil amendments, microbial inoculants, compost teas, microbial food sources, and topdressing as needed with high-quality finished compost.

- **Grass maintenance**: Maintain turf health through specific cultural practices, including appropriate mowing, aeration, irrigation, and over-seeding. Address trouble spots through composting and re-sodding where necessary.

It is important to note that organic turf management requires proper training. Conventional turf management may follow a similar protocol each year; organic turf managers make adjustments based on changing conditions.

Installation/Maintenance Costs: Comparing Artificial Turf with Natural Grass

In analyzing the costs of artificial vs. natural grass systems, it is important to consider full life cycle costs, including installation, maintenance, and disposal/replacement. Artificial turf systems of all types require a significant financial investment at each stage of the product life cycle. In general, the full life cycle cost of an artificial turf field is higher than the cost of a natural grass field.

Cost information is available through university entities, turf managers' associations, and personal communications with professional grounds managers. Information is also available on the relative costs of conventional vs. organic management of natural grass.

Installation

According to the Sports Turf Managers Association (STMA), the cost of installing an artificial turf system may range from $4.50 to $10.25 per square foot. For a football field with a play area of 360x160 feet plus a 15-foot extension on each dimension (65,625 square feet), this yields an installation cost ranging from about $295,000 to about $673,000. These are costs for field installation only, and full project costs may be higher. Costs for a larger field would also be higher. A range of choices in materials and underlayments can influence the total cost of the field.

In one site-specific example, information provided by the town of Natick, Massachusetts, shows that the full project budget for the installation in 2015 of a new artificial turf field (117,810 square feet), along with associated landscaping, access and site furnishings, totaled $1.2 million.[90]

For natural grass, installation of a new field may not be necessary. For communities that do choose to install a new field, costs can range from $1.25 to $5.00 per square foot, depending on the type of field selected. For the dimensions noted above, this would yield an installation cost ranging from about $82,000 to about $328,000.[91]

Maintenance

Maintenance of artificial turf systems can include fluffing, redistributing and shock testing infill; periodic disinfection of the materials; seam repairs and infill replacement; and watering to lower temperatures on hot days. Maintenance of natural grass can include watering, mowing, fertilizing, replacing sod, and other activities. In both cases, specialized equipment is needed. Communities shifting from natural grass to artificial turf may need to purchase new equipment for this purpose. According to STMA, maintenance of an artificial turf field may cost $5,000 to $8,000 per year for materials and 300 to 500 hours of labor per year. These estimates are higher for artificial turf fields used for multiple sports. Maintenance of a natural grass field may cost $4,000 to $14,000 per year for materials plus 250 to 750 hours of labor.[92]

Organic turf maintenance can be cost-competitive with conventional management of natural grass. One study found that once established, an organic turf management program can cost 25% less than a conventional turf management program.[93]

Fifteen acres of playing fields in Marblehead, MA are managed organically. Annual maintenance costs are $2,400–$3,000 per 2-acre playing field, not including mowing costs. Mowing costs for a 2-acre field were estimated in 2010 to be $10,000 annually. Thus, total maintenance costs per 2-acre field are $12,400 to $13,000 annually (or $0.14 to $0.15 per square foot per year).[94]

Disposal/replacement

Artificial turf also requires disposal at the end of its useful life. STMA estimates costs of $6.50 to $7.80 per square foot for disposal and resurfacing.[95] Those estimates yield $426,000 to $512,000 for a

65,625 square foot field and $552,000 to $663,000 for an 85,000 square foot field.

Annualized costs

In 2008, a Missouri University Extension study calculated annualized costs for a 16-year scenario. The calculation included the capital cost of installation; annual maintenance; sod replacement costing $25,000 every four years for the natural fields; and surface replacement of the synthetic fields after eight years. Based on this calculation, a natural grass soil-based field is the most cost effective, followed by a natural grass sand-cap field, as shown in Table 5.[96] Another study, conducted by an Australian government agency, found that the 25-year and 50-year life cycle costs for artificial turf are about 2.5 times greater than those for natural grass.[97]

Planning over time

Each municipality or institution will face its own considerations as it works to develop plans for athletic fields. Some municipalities are working from a baseline of an existing, poorly-maintained grass field, or a field with poor drainage, and may wish to research options for upgrading these existing resources. In planning for the medium term, it is necessary to have a maintenance plan, whether the field is grass or artificial. For an artificial turf field, the community also needs to plan for disposal.

Summary

In summary, when the full product life cycle is taken into account, natural grass is likely to be more cost effective than artificial turf. Organic management of natural grass can further lower costs over time by building healthy soil and robust root systems. When assessing the cost of any option, whether natural grass or artificial turf, it is also important to note that there can be cost gradations depending whether a basic or a premium field is needed. More detailed cost information is also available on TURI's website.[98]

Organic Management of Playing Fields: Springfield, MA

The city of Springfield, Massachusetts, manages many of its sports fields organically. According to the Springfield Parks Department, organic management has improved the overall condition of these fields. Many hours of both formal and informal sports play occur on these fields, and there are few or no cancellations due to weather-related field conditions.[99]

Forest Park, Springfield, MA, 2018.

The consultant working with Springfield was able to provide TURI with cost figures for the first three years of organic management. The cost was $1,740/acre in the first year, $1,245/acre in the second year, and $1,110/acre in the third year. Thus, maintenance costs decreased each year as the health of the soil and vegetation improved.[100]

The consultant was also able to provide an estimate of the hours of play on one of the organically managed fields. The field has 650 scheduled hours annually. In addition to this, physical education classes are held on the field and there is an estimated 100 hours of non-programmed use. The consultant estimated that this adds up to a total of about 1,000 hours of field use per year.[101]

Conclusions

Artificial turf poses a number of health and environmental concerns. Those communities that have decided to install artificial turf are encouraged to make careful choices among the materials available to them. This is likely to include requiring some additional testing to get information on organic compounds as well as metals. Communities should bear in mind that existing tests apply only to the sample on which they are conducted, and materials used in artificial turf may vary widely in composition. From an environmental and health standpoint, organically managed natural grass is a safer choice for sports fields. When the full product life cycle is considered, organically managed natural grass also offers lower costs over time.

Glossary of Acronyms

ATSDR	Agency for Toxic Substances and Disease Registry
CPSC	Consumer Product Safety Commission
EPA	US Environmental Protection Agency
EPDM	Ethylene propylene diene terpolymer
FDA	US Food and Drug Administration
IPM	Integrated pest management
NBI	Norwegian Building Institute
OEHHA	California Office of Environmental Health Hazard Assessment
PAHs	Polyaromatic hydrocarbons
$PM_{2.5}$	Particulate matter with diameter less than 2.5 micrometers
REACH	European Union's Registration, Evaluation and Authorisation of Chemicals
RIVM	National Institute for Public Health and the Environment (Netherlands)
RSLs	Restricted Substances Lists
SBR	Styrene Butadiene Rubber
STMA	Sports Turf Managers Association
SVOCs	Semi-volatile organic compounds
TPE	Thermoplastic elastomer
TUR	Toxics Use Reduction
TURI	Massachusetts Toxics Use Reduction Institute
TVOCs	Total volatile organic compounds
VOCs	Volatile organic compounds
WET	Whole effluent toxicity

[1] Toxics Use Reduction Institute. 2018. "Artificial Turf: Selecting Safer Alternatives for Athletic Playing Fields." Available at www.turi.org/artificialturf. Also see Toxics Use Reduction Institute. 2018. "Organic Lawn Care Projects," available at https://www.turi.org/Our_Work/Community/Topic_Areas/Organic_Lawn_Care_Projects, and "Organic Lawn Care," available at https://www.turi.org/Our_Work/Community/Organic_Lawn_Care.

[2] Landrigan P. 1998. "Environmental Hazards for Children in USA." *International Journal of Occupational Medicine and Environmental Health* 11:2, 189-94.

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Comparison of WBGTs over Different Surfaces within an Athletic Complex

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Abstract: Many athletic governing bodies are adopting on-site measurement of the wet-bulb globe temperature (WBGT) as part of their heat safety policies. It is well known, however, that microclimatic conditions can vary over different surface types and a question is whether more than one WBGT sensor is needed to accurately capture local environmental conditions. Our study collected matched WBGT data over three commonly used athletic surfaces (grass, artificial turf, and hardcourt tennis) across an athletic complex on the campus of the University of Georgia in Athens, GA. Data were collected every 10 min from 9:00 a.m. to 6:00 p.m. over a four-day period during July 2019. Results indicate that there is no difference in WBGT among the three surfaces, even when considered over morning, midday, and afternoon practice periods. We did observe microclimatic differences in dry-bulb temperature and dewpoint temperature among the sites. Greater dry-bulb and lower dewpoint temperatures occurred over the tennis and artificial turf surfaces compared with the grass field because of reduced evapotranspiration and increase convective transfers of sensible heat over these surfaces. The lack of difference in WBGT among the surfaces is attributed to the counterbalancing influences of the different components that comprise the index. We conclude that, in a humid, subtropical climate over well-watered grass, there is no difference in WBGT among the three athletic surfaces and that, under these circumstances, a single monitoring site can provide representative WBGTs for nearby athletic surfaces.

Keywords: athletic surfaces; WBGT; weather; heat stress; safety

1. Introduction

Exertional heat illnesses (EHI) affect thousands of athletes each year and exertional heat stroke is among the leading causes of death among athletes [1]. Environmental monitoring coupled with activity modification is a key component of a well-designed heat policy [2,3]. Importantly, on-site measurements can better capture local microclimate conditions than remote observations from weather stations as differences in sheltering, surface type, or solar exposure can influence heat stress [4–6]. As such, regarding the interscholastic participant, numerous high school athletic associations now require on-site measurement of environmental conditions using the wet-bulb globe temperature (WBGT) [7]. A question that has been raised among sports medicine professionals is whether a single weather measurement can represent environmental conditions on nearby athletic fields when there are a variety of surfaces (e.g., grass, artificial turf, hardcourt tennis, etc.) used for athletic play or if measurements are required over each surface. Microclimatic conditions over small areas can be greatly affected by the characteristics of the underlying surface [8]. Multiple studies have identified that athletic surface type, especially artificial turf, alter surface temperatures relative to grass covered surfaces, and which may affect heat stress [9–13]. What has been less explored is how these surface changes impact ambient air temperatures and humidity levels above the athletic surfaces and integrated bioclimatic indices like

the WBGT [5,14–16]. Both the cost of WBGT sensors and the staffing to monitor multiple sensors may pose barriers to high schools or other organizations adopting the practice of monitoring environmental conditions where multiple sites are used. Our study seeks to identify if different athletic surfaces, which are commonly present on high school and college campuses, and other athletic/recreational facilities may affect WBGT measurements. In particular, we ask two key questions:

(1) Does the WBGT vary by athletic surface (artificial turf, hardcourt tennis, and grass)?
(2) Is a single monitoring station able to capture local WBGT conditions in an athletic complex?

2. Materials and Methods

WBGT data were collected over three different surface types commonly associated with the sports of American football, soccer, and tennis on the campus of the University of Georgia (UGA) in Athens, GA, USA over a five-day period, 24–28 July, 2019 (Figure 1). Athens, GA has a humid, subtropical climate characterized by hot and humid summers [17]. Data were collected over commonly used athletic surfaces, including natural grass, artificial turf (FieldTurf, Montreal, QC, Canada), and hardcourt tennis (Plexipave, Andover, MA, USA) surfaces, which were all located between 162 and 423 m of each other. The natural grass surface was well watered. The day before the study (23 July), 3.56 mm of precipitation was recorded at the on-site WeatherSTEM station and the grass field was watered between 2:30 a.m. and 3:30 a.m. on two days (26 and 28 July) during the study. Three WBGT monitors (Kestrel 5400 heat stress meters, Nielsen-Kellerman, Boothwyn, PA, USA) were set on a tripod at each site in a sunny location that would not be subjected to shade (other than cloud cover) during the data collection period. In addition, the locations we selected were at least 15 m from another surface type and had sheltering that would reduce the effects of local advection. The tennis court, for instance, is located adjacent to an asphalt parking lot but is separated by a mesh covered fence that would reduce wind speeds.

Figure 1. Map of study locations with site photographs. The distance between tennis and grass surfaces is 424 m, artificial turf and tennis surfaces is 317 m, and artificial turf and grass surfaces is 162 m. WxSTEM refers to the on-site weather station.

Over each surface, the WBGT monitors were set up on the tripods at 1.2 m above the surface to represent an anthropometric scale [18]. The dry-bulb temperature, natural wet-bulb temperature, globe temperature, dewpoint temperature, and wind speed were collected every 10 min from

9:00 a.m. to 6:00 p.m. The WBGT was computed as a weighted average of the dry-bulb temperature (DB), natural wet-bulb temperature (WB), and globe temperature (GT) using the following equation [19]:

$$WBGT = 0.7 \times WB + 0.2 \times GT + 0.1 \times DB. \quad (1)$$

We followed the manufacturer's recommendation and allowed the unit to equilibrate for 15 min prior to collecting data for analysis [20]. Observations with relative humidity <15% or >95% were removed from the dataset as they exceed the specification range for sensor accuracy [21]. For comparison purposes, only times when all three surfaces had viable observations were retained. In total, 243 observations from each surface were compared. These observations were divided into three different practice periods: morning (9:00–11:59 a.m., n = 63), midday (noon–2:59 p.m., n = 90), and afternoon (3:00–5:59 p.m., n = 90). Weather data (e.g., temperature, humidity, wind speed, and solar radiation) were collected from a WeatherSTEM station that is located within the sports complex (Figure 1). This weather dataset was used to identify the overall weather conditions during the study days [22].

Summary statistical measures were used to quantify WBGTs and other meteorological variables among the surfaces, with a focus on median for central tendency and interquartile range for variability as not all data distributions were normal. Normality was determined using the Kolmogorov–Smirnov test and visual inspection of the Q–Q plot and histogram. Pearson's correlation coefficient was used to assess the association of WBGTs between the surfaces (i.e., grass vs. artificial turf; grass vs. tennis, and artificial turf vs. tennis) and the relationship between the WBGT over a particular surface with weather station data (e.g., temperature, dewpoint temperature, wind speed, and solar radiation). ANOVA (or Kruskal–Wallis one-way analysis of variance on ranks when the required assumptions were not met) was used to compare the effect of athletic surface type on WBGT values using $\alpha = 0.05$. A similar approach was used to assess the effect of surface type on the WBGT components as well as dewpoint temperature. All statistical analyses were completed using SPSS (version 26; IMB Corp, Armonk, NY, USA).

3. Results

3.1. Weather Conditions

Weather conditions were determined from a centrally located weather observing station (Figure 1). Over the five-day study, maximum air temperatures ranged from 30.3 to 32.6 °C and minimum temperatures were between 17.7 and 20.2 °C (Figure 2a). Average daily dewpoint temperature varied from 15.6 to 19.4 °C (Figure 2a). Maximum solar radiation exceeded 1000 W m^{-2} each day (1032–1097 W m^{-2}) with considerable variability, particularly in the afternoon in response to changing cloud cover (Figure 2b). Based on 11 years (2009–2019) of July data from a nearby weather station at the UGA Climatology Research Laboratory (~1.8 km from study site with a longer period of record than the WeatherSTEM station), the study days had lower than average maximum daytime temperatures (long-term mean = 33.2 °C) and humidity (long-term mean = 22.5 °C) but peak solar radiation values that were close to average.

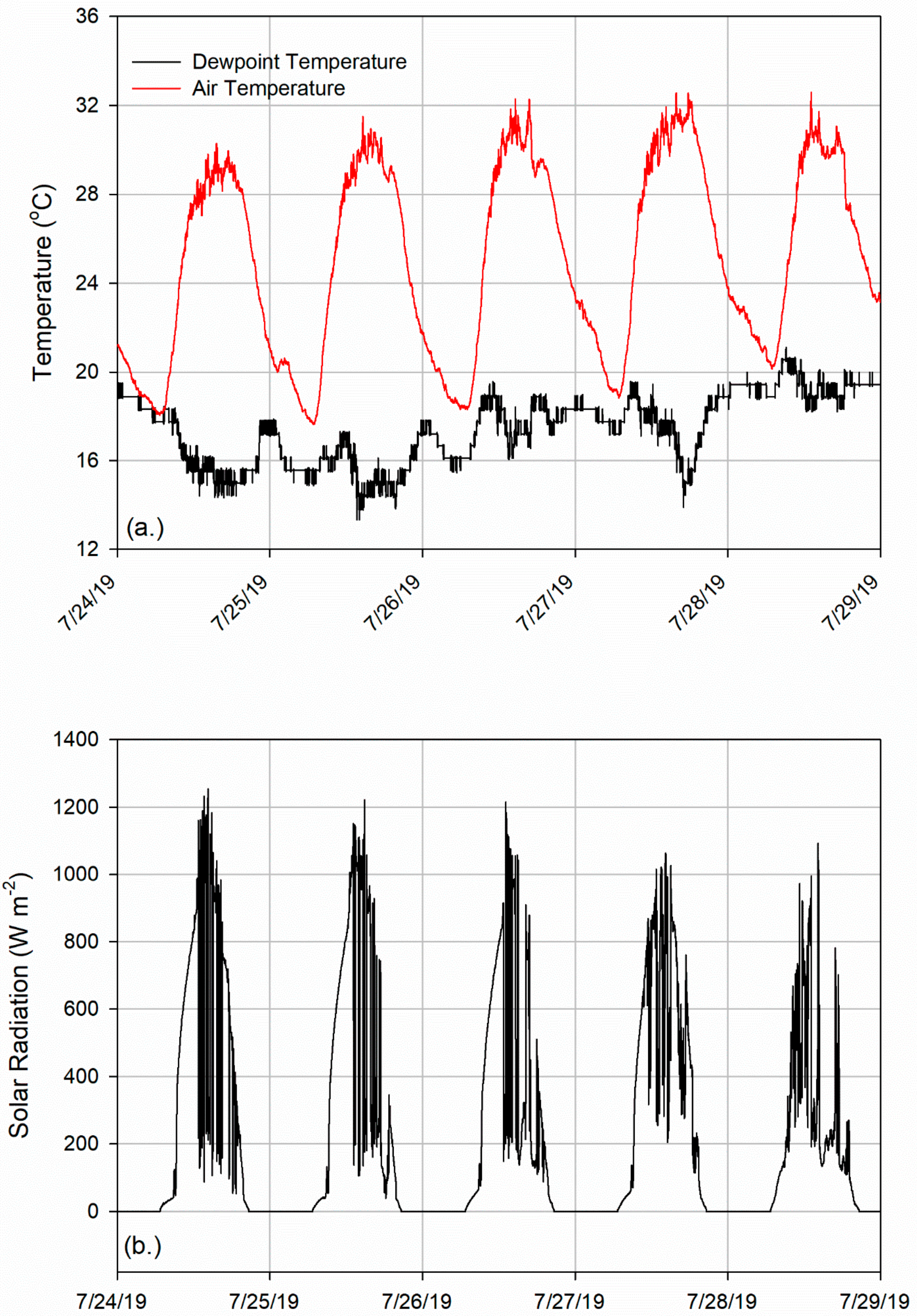

Figure 2. Weather conditions at on-site WeatherSTEM observing station: (**a**) air temperature and dewpoint temperature and (**b**) solar radiation.

3.2. Differences in WBGT among Athletic Surfaces

A wide variety of WBGTs occurred over the study period, ranging from as low at 22.9 °C up to 32.2 °C (Figure 3). In the morning period, median WBGTs ranged between 25.94 and 26.83 °C among the surfaces with median values slightly greater (0.78–0.89 °C) over grass than tennis or artificial turf surfaces, respectively. During the midday period, median WBGTs were greater relative to both the morning and afternoon practice times, with values ranging from 27.33 to 27.67 °C. This period had the smallest difference among median WBGTs, with artificial turf 0.06 °C greater and tennis 0.33 °C greater than grass. Finally, WBGTs decreased in the afternoon period relative to midday, with median values between 25.83 and 26.42 °C. Both artificial turf and tennis surfaces had slightly greater WBGTs than grass by approximately 0.56–0.58 °C. The afternoon had the largest variance of WBGTs values with the interquartile (75th–25th percentile) range from 3.01 to 3.19 °C compared with 2.33–2.89 °C for morning and 2.51–2.81 °C for midday. The athletic surface type did not have a significant effect on WBGT at the $p < 0.05$ level in any of the practice periods: $F(2,186) = 2.828$, $p = 0.062$ for morning, $F(2,267) = 0.254$, $p = 0.776$ for midday, and $F(2,267) = 0.831$, $p = 0.437$.

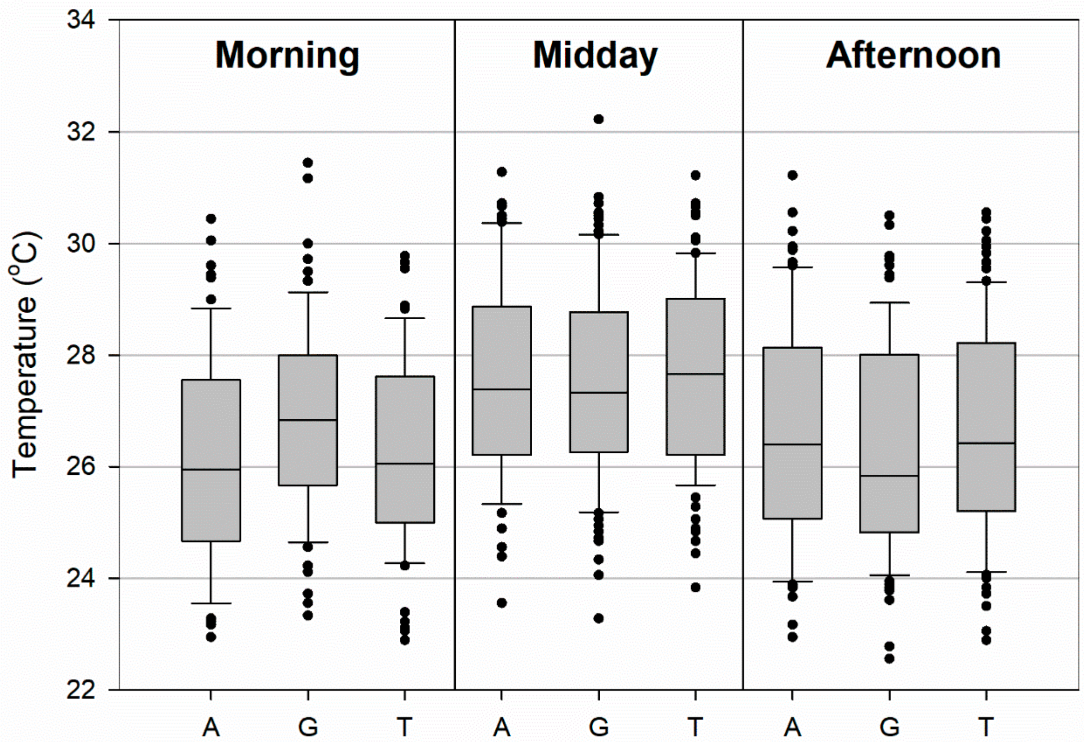

Figure 3. Box plots of wet-bulb globe temperature (WBGT) for artificial turf (A), grass (G), and hardcourt tennis (T) athletic surfaces for morning (9:00–11:59 a.m.), midday (noon–2:59 p.m.), and afternoon (3:00–5:59 p.m.) practice sessions. The boundaries of the box represent the 25th and 75th percentiles, the line within the box indicates the median, the whiskers are the 10th and 90th percentiles, and the points above and below are the outliers, respectively.

We observed strong correlations between the WBGTs of each surface, ranging from $r = 0.89$–0.92 in the morning, 0.81–0.90 during midday, and 0.90–0.93 in the afternoon. This is well illustrated in Figure 4 for 26 July between 11:00 a.m. and 5:59 p.m. where WBGTs over each surface type vary together in close association with recorded solar radiation levels. Of note are the large swings in WBGT by up to 5–6 °C in magnitude over short time periods (10 min) in response to changing solar radiation. In fact, over the study period, WBGTs were most highly correlated with changes in solar radiation (r = 0.60–0.66; Table 1). There were smaller correlations between WBGTs and air temperature (0.32–0.52) and dewpoint temperature (0.15–0.23).

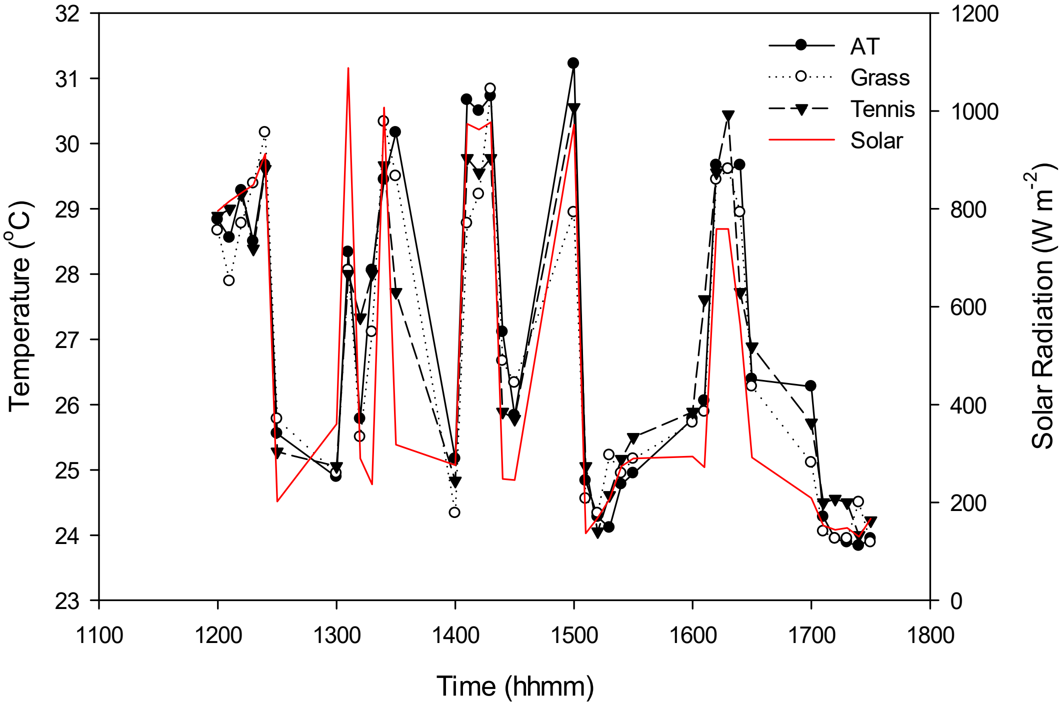

Figure 4. WBGTs and solar radiation by athletic surface for 26 July 2019 during the midday and afternoon periods. AT is artificial turf.

Table 1. Athletic surface WBGT correlations (n = 242 observations) with weather variables measured at the on-site WeatherSTEM observing station. AT is artificial turf.

	AT WBGT	Grass WBGT	Tennis WBGT
Dry-bulb Temperature	0.52	0.32	0.50
Dewpoint Temperature	0.22	0.23	0.15
Solar Radiation	0.60	0.65	0.66

3.3. *Differences in Microclimates among Athletic Surfaces*

We observed differences in the component parts of the WBGT as well as dewpoint temperature among the surfaces in the different time periods (Figure 5). In the morning, artificial turf and tennis have slightly warmer median dry-bulb temperatures (0.56–0.61 °C), but median dewpoints were 0.95–1.17 °C lower and wet-bulb temperatures were 0.61–0.94 °C lower than grass (Figure 5a). Median globe temperatures were greater over grass (+0.94 °C) and tennis (+0.72 °C) surfaces than artificial turf. The athletic surface type had a statistically significant effect on dewpoint temperature ($F(2,186)$ = 3.583, p = 0.030). Post hoc comparisons using the Tukey HSD test indicated that the mean score was significantly different between grass and tennis surfaces (M = 0.732, p = 0.027). In addition, the surface type had a significant effect upon wet-bulb temperature ($F(2,186)$ = 4.970, p = 0.008), with post hoc comparisons indicating that the mean value was significantly different between tennis and grass surfaces (M = −0.722, p = 0.022) and between artificial turf and grass surfaces (M = −0.7469, p = 0.017).

During midday, artificial turf and tennis surfaces had greater median dry-bulb temperatures by 0.83 to 1.06 °C, but dewpoints were 0.91 to 1.11 °C lower, and wet-bulb temperatures were 0.28 to 0.44 °C lower than measurements taken over grass. Median globe temperatures were greater (+1.42 to 1.53 °C) over the artificial turf and tennis court surfaces than the grass field (Figure 5b). The interquartile differences for the globe temperature over the three surfaces (approximately 6–8 °C) were greater than for dry-bulb, dewpoint, and wet-bulb temperatures (approximately 2–3 °C), indicating the greater dispersion of observations. Unlike in the morning, the athletic surface type had a statistically significant effect on dry-bulb temperatures ($F(2,267)$ = 9.502, p = 0.000). Post hoc comparisons using the Tukey

HSD test indicated that the mean dry-bulb temperature was significantly different between artificial turf and grass surfaces (M = 0.836, p = 0.001) and between tennis and grass (M = 0.934, p = 0.000). In addition, the surface type had a significant effect upon the dewpoint temperature (H(2) = 16.60, p = 0.000). Results from the pairwise tests using the Bonferroni correction show significant differences between tennis and grass (p = 0.001) and artificial turf and grass (p = 0.002) with respect to dewpoint measurements. Surface type had a significant effect upon globe temperatures (H(2) = 6.22, p = 0.045) but pairwise tests using the Bonferroni correction do not show any significant differences. This may have occurred because of the weakly significant global effect with the p-value near the 0.05 threshold.

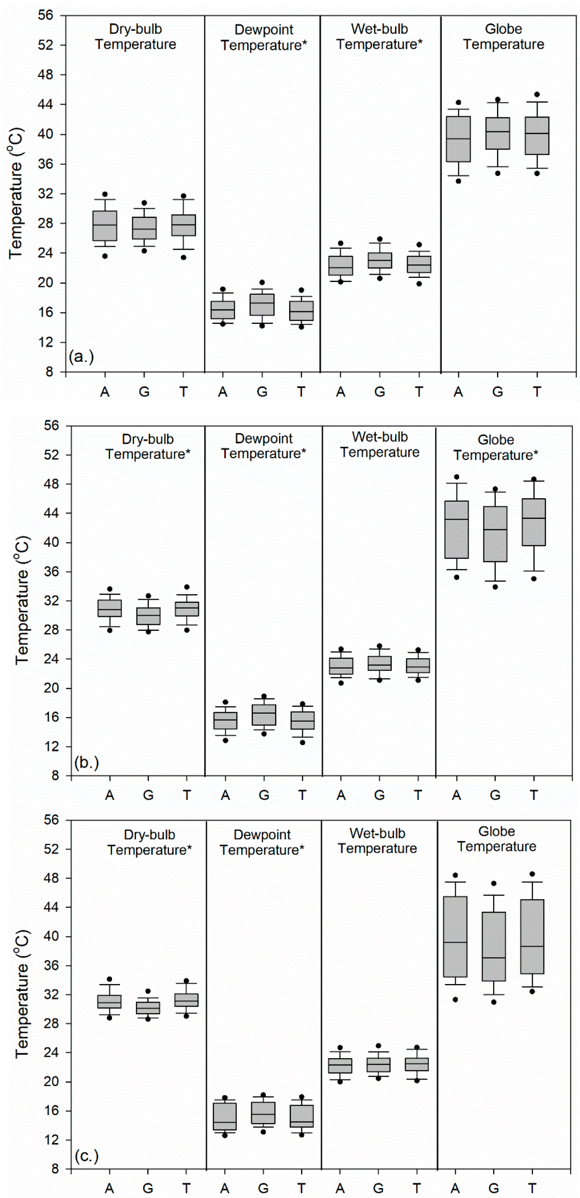

Figure 5. Box plots of WBGT components and other meteorological variables among artificial turf (A), grass (G), and hardcourt tennis (T) athletic surfaces for (**a**) morning (9:00–11:59 a.m.), (**b**) midday (noon–2:59 p.m.), and (**c**) afternoon (3:00–5:59 p.m.) practice sessions. The boundaries of the box represent the 25th and 75th percentiles, the line within the box indicates the median, the whiskers are the 10th and 90th percentiles, and the points above and below the whiskers are the 5th and 95th percentiles, respectively. Note that surface type had a statistically significant effect upon globe temperatures during midday but pairwise tests do not show any significant differences. * indicates statistically significant at $p < 0.05$.

Finally, during afternoon practices, artificial turf and tennis surfaces had greater median dry-bulb temperatures (0.81 to 1.00 °C) but lower dewpoint (1.06 to 1.09 °C lower) and wet-bulb temperatures (0.08 to 0.11 °C lower) than over grass (Figure 5c). Median globe temperatures were 1.61 to 2.19 °C greater over artificial turf and tennis surfaces than grass. The interquartile range for the globe temperature over the three surfaces (approximately 9–11 °C) are greater than for dry-bulb, dewpoint, and wet-bulb temperatures which are about 2–4 °C. Similar to midday, the athletic surface type had a statistically significant effect on dry-bulb temperatures ($H(2) = 30.147$, $p = 0.000$). Results from the pairwise tests using the Bonferroni correction show significant differences between artificial turf and grass ($p = 0.000$) and tennis and grass ($p = 0.000$) surfaces. The surface type also had a significant effect upon the dewpoint temperature ($H(2) = 9.486$, $p = 0.009$). Results from the pairwise tests using the Bonferroni correction show significant differences in dewpoint temperature between artificial turf and grass ($p = 0.015$) and tennis and grass ($p = 0.037$) surfaces.

4. Discussion

We did not find a difference in median WBGTs among three different athletic surfaces during any of the three practice periods. However, microclimatic differences in dry-bulb temperature, dewpoint temperature, and wet-bulb temperature among the surfaces were observed at various times and help to explain the lack of difference in WBGT.

In the morning, we found statistically significant differences in dewpoint temperature and wet-bulb temperature but no difference in dry-bulb or globe temperatures. Grass and the underlying soil can add moisture to the air via evapotranspiration, increasing dewpoint temperatures compared with impervious surfaces, like the tennis court or artificial turf surfaces, that are designed to quickly drain away water [13,23]. The wet-bulb temperature is a function of multiple variables, including solar radiation, dry-bulb temperature, wind speed, and humidity [24]. Given no statistical difference in dry-bulb temperature and solar radiation among surfaces during this period, the greater wet-bulb temperature over grass is driven by the greater atmospheric moisture as indicated by the higher dewpoint temperature.

During midday and afternoon, we observed statistically significant differences among surfaces in dry-bulb and dewpoint temperatures. The artificial turf and tennis surfaces had greater median dry-bulb but lower dewpoint temperatures than the grass surface. The hotter dry-bulb temperature is in line with previous research and associated the greater transfers of sensible heat via convection of hotter air from the drier surfaces [13–15]. As in the morning, the greater dewpoint temperature over the grass field is related to the evapotranspiration of moisture into the lower atmosphere. The lack of significant difference in wet-bulb temperature is due to counteracting factors. As mentioned above, wet-bulb temperature is a function of multiple meteorological variables. Over the artificial turf and tennis surfaces, the greater dry-bulb temperature would serve to increase the wet-bulb temperature, but the lower dewpoint temperature would offset this increase. In contrast, the lower dry-bulb temperature over the grass surface would decrease the wet-bulb temperature, but this would be offset by the greater dewpoint temperature. This finding is different than observed by Kandelin et al. (1976) who observed a greater wet-bulb temperature over artificial turf when compared with a grass field [14]. An explanation for this is that the Kandelin study did not measure humidity independently over each surface but rather used one measurement. Thus, the higher wet-bulb temperatures over the artificial turf are driven by the greater air temperatures. Lastly, the globe temperature is determined by several factors including solar radiation, air temperature, and wind [24]. While the greater dry-bulb temperatures over the tennis and artificial turf surfaces may slightly increase the globe temperature, the small overall difference among surfaces is likely due to the similar solar radiation inputs experienced by the nearby study sites. In sum, given the high weight of the wet-bulb temperature (which was not different among sites) in the WBGT computation, the small differences in dry-bulb and globe temperatures did not lead to a statistically significant difference in the WBGT.

Our findings are consistent with those of Kopec (1977) who also compared WBGT among different surface types (e.g., hardcourt tennis, artificial turf, and grass) in a similar humid subtropical climate [16]. He observed only small differences in WBGT between the grassy control site and other sites, likely due to counteracting variables in the WBGT equation and the heavy weighting of the wet-bulb temperature component. For instance, a detailed case study between the grassy control site and an artificial turf field showed that the artificial turf surface had greater average dry-bulb and globe temperatures but a slightly lower wet-bulb temperature. The magnitude of the average differences in both dry-bulb (2.2 °C) and globe temperatures (3.6 °C) were greater than those found in this study, however. Possible explanations may be the differences in thermal characteristic of the artificial turf surfaces (Astroturf vs. FieldTurf), the short period of the Kopec's case study (two hours on a single day), and the distance between sites which could influence solar radiation. In fact, Kopec (1977) hypothesized that solar radiation in response to changing cloud cover rather than surface type was the key driver of WBGT variations between sites in his study. We similarly found that changes in solar radiation were highly correlated with WBGT and resulted in large swings in values, regardless of surface, over short time periods. However, the nearness of our three sites allowed us to control for solar radiation as a factor in explaining instantaneous differences in WBGT.

In our study, we identified some limitations that may impact our findings. First, our study was performed in a humid, subtropical climate with a well-watered grass surface. Further research is needed to confirm if our findings can be more broadly applied to conditions when the grass surface may have low soil moisture, whether due to a drought or the prevailing climate (e.g., arid region), which could influence evapotranspiration and low-level moisture [25]. Second, we focused on three common athletic surface types. While further work is needed to confirm our findings over different surfaces such as rubberized track surfaces or brick dust often used with baseball and softball infields, our work is suggestive that variability in solar radiation creates larger WBGT variations within surface type than between surface type. Third, our study focused narrowly on whether WBGT varied by athletic surface type. We cannot conclude there is no difference in heat stress to athletes among athletic surfaces. In addition, our results should not be generalized to other heat indices. Other measures, such as the heat index, have different assumptions and input variables than the WBGT, which could affect whether there are meaningful differences in the index values among athletic surfaces. Finally, our results are applicable to nearby sites (less than 0.5 km). Longer distances may influence solar radiation variability between sites.

5. Conclusions

Our study indicates that in a humid, subtropical climate over a well-watered grass field, there is no difference in WBGT when compared to artificial turf and hardcourt tennis surfaces. Yet, there are clear microclimatic differences in dry-bulb and dewpoint temperatures among the three surfaces that provide counterbalancing influences on components of the WBGT, ultimately limiting the total difference in the index. Thus, a single monitoring site is sufficient to capture representative WBGTs over a variety of commonly used athletic surfaces in close proximity, when meeting our study conditions.

Author Contributions: Conceptualization, A.G. and E.C.; methodology, A.G. and E.C.; analysis, A.G. and E.C.; writing, A.G. and E.C. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

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Characterization of synthetic turf rubber granule infill in Japan: Polyaromatic hydrocarbons and related compounds

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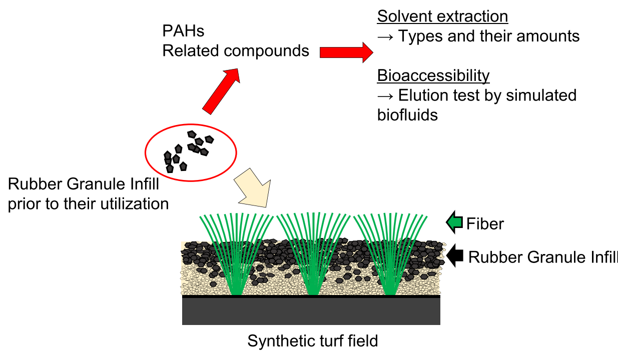
HIGHLIGHTS

- PAHs and related compounds in rubber infill for use in synthetic turf were studied.
- Tire samples had higher PAH concentrations than industrial rubber samples.
- The maximum PAH concentrations were equal to or less than those obtained previously.
- The concentration of eight PAHs regulated in EU was lower than the limit value.
- For all PAHs and their analogues, the elution amount was less than the LOQ.

GRAPHICAL ABSTRACT



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ABSTRACT

Although the health effects of artificial turf fillings have been investigated in Europe and the United States, the actual situation in Japan is unclear. To address this issue, the concentrations of 46 polyaromatic hydrocarbons (PAHs) and related compounds in rubber infills were analyzed prior to their use in synthetic turf fields in Japan. Based on information obtained from the sample suppliers, the investigated samples were divided into five categories: discarded tires, industrial rubber, combinations of these products or unidentified components (mixture/unknown), synthetic rubber specifically manufactured for synthetic turf, and special-purpose thermoplastic elastomers (TPEs). The industrial rubber samples were mixtures of styrene butadiene rubber, natural rubber, and ethylene propylene diene rubber (EPDM). The synthetic rubber samples consisted only of EPDM. A few or none of the PAHs were detected in the synthetic rubber and TPE samples. However, in the discarded tire and industrial rubber samples, benzo[*a*]pyrene, cyclopenta[*cd*]pyrene, and 30 other compounds were detected. A comparison between these two categories indicated that the discarded tire samples exhibited higher concentrations of the target compounds than the industrial rubber samples. This finding can be attributed to the presence of EPDM in almost all of the industrial rubber samples, which were not present in the discarded tire samples. The maximum PAH concentrations obtained in the present study were equivalent to or lower than the previously reported PAH concentrations. The total concentrations of the eight PAHs included in the European Chemical Agency (ECHA) assessment of health risks were lower in the present

Abbreviations: PAHs, polyaromatic hydrocarbons; TPEs, thermoplastic elastomers; EPDM, ethylene propylene diene rubber; ECHA, European Chemical Agency; JFA, Japan Football Association; FIFA, International Federation of Association Football; SBR, styrene butadiene rubber; USEPA, United States Environmental Protection Agency; ECHA, European Chemicals Agency; NR, natural rubber; IARC, International Agency for Research on Cancer; LOQ, limit of quantification.

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study than those reported by the ECHA. Furthermore, elution testing was performed with four simulated biofluids (gastric and intestinal juices, saliva, and perspiration). The actual elution amounts of all compounds were less than the limits. This report provides basic data for the risk assessment of PAHs in rubber infills.

1. Introduction

In recent years, the ease of maintenance and low cost of operation of synthetic turfs have incentivized their use in sports such as soccer and baseball, school playgrounds, and parks mainly used by children. Synthetic turf composites used in competitive soccer fields contain synthetic grass blades composed of long resin piles (length ≥ 50 mm) with a granular infill material (Japan Football Association (JFA), 2017). The rubber granules or silica-sand infills help hold the turf fibers upright and enhance their cushioning effect. Although some types of crumbed rubber are specifically manufactured for synthetic turf fields, most of them are produced by recycling discarded tires and industrial rubber products.

The chemicals contained in (or leached from) rubber granules pose certain health hazards, and numerous studies have reported the elution of chemicals from rubber granules (Avagyan et al., 2013; Celeiro et al., 2014; Li et al., 2010; Llompart et al., 2013; Nilsson et al., 2008; Plesser and Lund, 2004). Additionally, when playing on synthetic turf, the rubber granules may adhere to the skin, enter via the mouth, or be inhaled. In 2006, the International Federation of Association Football (FIFA) noted that although the carcinogenic risk of the styrene butadiene rubber (SBR) used in synthetic turf fields was unproven, they would continue collecting information (FIFA, 2006). In 2014, American news channel NBC reported on the relationship between the incidence of cancer in female soccer players and rubber granules on synthetic turfs (NBC, 2016), which increased public concern regarding the use of rubber granules derived from discarded tires. In February 2016, the United States Center for Disease Control, Agency for Toxic Substances and Disease Registry, United States Environmental Protection Agency (USEPA), and Consumer Product Safety Commission started investigating the safety of rubber granules produced from discarded tires, which are used as infill in synthetic turf; however, the study is still underway (USEPA, 2016a). The European Chemicals Agency (ECHA, 2017) and the Netherlands National Institute for Public Health and the Environment (RIVM, 2017) also investigated the potential health risks associated with recycled rubber granules in synthetic turf infill. Recently, a Europe-wide study, the European Risk Assessment Study on Synthetic Turf Rubber Infill, was performed by industrial associations and related companies; the study involved the risk assessment of synthetic turf rubber infill (Schneider et al., 2020a, 2020b, 2020c). Recently, the ECHA noted that synthetic turf infills are among the major sources of microplastic emissions, and that their effects on the environment and human health are of concern (ECHA ANNEX XV, 2021; ECHA hot topic 2, 2021). Although the health effects of artificial turf fillings have been investigated in Europe and the United States, the actual situation in Japan is unclear. Therefore, we conducted several studies to assess the effect of rubber granules in synthetic turfs on the health of athletes, other players, and children in Japan.

Polyaromatic hydrocarbons (PAHs) are among the high-concern chemicals present in rubber infills; therefore, these compounds have been investigated in previous studies (Armada et al., 2022; Avagyan et al., 2013; Celeiro et al., 2014; ECHA, 2017; Li et al., 2010; Llompart et al., 2013; Nilsson et al., 2008; Plesser and Lund, 2004; RIVM, 2017; Schneider et al., 2020a; USEPA, 2016a). Furthermore, since August 2022, the European Union will restrict the combined concentration of PAHs in rubber granulate used as infill material to a maximum of 20 mg/kg for the sum of eight PAHs listed in Annex XVII of regulation (EC) number 1907/2006 (subsequently referred to as eight REACH PAHs) (European Union , 2021).

The objectives of the present study were to elucidate the types and compositions of PAHs and related compounds present in rubber infill products prior to their utilization in synthetic turf and to investigate their elution characteristics in four simulated biofluids (gastric juice, intestinal juice, saliva, and perspiration). In this study, compounds containing heterocycles or substituents in addition to PAHs and compounds that were not PAHs but had multiple benzene rings were included in the analysis as “related compounds.” The data obtained in this study can be used in subsequent risk assessment studies.

2. Materials and methods

2.1. Samples

The test materials included 46 products obtained from 10 synthetic turf field contractors in 2016 (Table 1). These 10 contractors cover >95 % of the market share in Japan. Based on information obtained from the contractors, the products were divided into five categories: discarded tires (n = 24, including 3 coated), industrial rubber (n = 10, including 2 coated), combinations of these products or unidentified components (mixture/unknown, n = 3, including 1 coated), synthetic rubber manufactured specifically for synthetic turf (consisting only of ethylene propylene diene rubber, EPDM) (n = 5), and special-purpose thermoplastic elastomer (TPE) (n = 4, including 3 coated). The discarded tire samples were mixtures of SBR and natural rubber (NR). The industrial rubber samples and mixture/unknown samples were mixtures of SBR, NR, and EPDM. All products were unused and ready to use. The particle sizes of the samples ranged from 0.5 to 3.2 mm.

Given the nature of recycling, the rubber granules present in a single product may have multiple origins, and the rubber samples were thoroughly mixed before testing.

2.2. Reagents

In this study, 46 PAHs and related compounds (Table 2) were selected for comparison with previously reported values and results obtained in other countries. In particular, we focused on compounds with International Agency for Research on Cancer (IARC) carcinogenic risk (IARC, 2016) classification of 2 B (suspected carcinogen) or higher, compounds subjected to restrictions in other countries, compounds that have been the focuses of overseas papers on carcinogenicity, and compounds that have been subjected to USEPA investigations.

The PAHs and related compounds to be measured were purchased from the producers listed in Table 2 (purity 97 % or higher). For quantitative analysis, a PAH reference standard (Quebec Ministry of Environment, polycyclic aromatic hydrocarbon mix; 500 μg/mL dichloromethane:benzene solution), which is a mixed standard solution procured from AccuStandard (Connecticut, USA), was used. The compounds present in the mixed standard solution are listed in Table 2. Compounds not contained in this standard solution product were previously described as standard materials and separately dissolved in toluene. Naphthalene-d_8 (C/D/N Isotope, Quebec, Canada), Acenaphthene-d10 (Wako Pure Chemical Industries, Ltd., Osaka, Japan), and Chrysene-d10 and Perylene-d12 (Kanto Chemical Co., Inc., Tokyo, Japan) were used as internal standards. Information regarding the other reagents used in this study is provided in the Supporting Information.

2.3. Elution testing solutions

The first and second fluids of the elution test liquids listed in the Japanese Pharmacopoeia (Ministry of Health, Labour and Welfare, 2016) were used as simulated gastric and intestinal juices, respectively. Simulated saliva and perspiration of acid sweats were prepared in accordance with the BS 6684 (British Standards Institution, 1987) and JIS L0848 (Japanese Standards Association, 2004) standards.

Table 1
Characteristics of rubber infill samples investigated in this study.

Sample no.	Origin	Material[a]	Coating	Color
1	Industrial rubber	SBR, EPDM	–	Black
2[b]	Discarded tire	NR, synthetic rubber[c]	–	Black
3	Industrial rubber	SBR	Polyurethane	Green
4	Discarded tire	SBR	–	Black
5	Synthetic rubber	EPDM	–	Green
6	Industrial rubber	Unknown	–	Green
7	Discarded tire	NR	–	Black
8	Discarded tire	NR	–	Black
9	Mixture/unknown	NR, SBR, BR, EPDM	–	Black
10	Synthetic rubber	EPDM	–	Beige
11	Synthetic rubber	EPDM	–	Green
12	Discarded tire	NBR, SBR	–	Black
13	Discarded tire	NBR, SBR	–	Black
14	Discarded tire	NBR, SBR	–	Black
15	Mixture/unknown	SBR	Polyurethane	Beige
16	Synthetic rubber	EPDM	–	Green
17	Industrial rubber	NR, SBR, NBR, EPDM	–	Black
18[b]	Industrial rubber	NR, SBR, NBR, EPDM	Polyurethane	Green
19	Discarded tire	SBR, NR	–	Black
20	Discarded tire	SBR, NR	–	Black
21	Discarded tire	Unknown	–	Black
22	Industrial rubber	SBR, EPDM	–	Black
23[b]	Industrial rubber	SBR, EPDM, NBR, NR	–	Black
24	Industrial rubber	NR, SBR, EPDM	–	Black
25	Thermoplastic elastomer	TPE	Talc	Green
26	Thermoplastic elastomer	TPE	Talc	Beige
27	Thermoplastic elastomer	TPE	Talc	Brown
28[b]	Discarded tire	SBR	Polyurethane	Beige
29[b]	Discarded tire	SBR	Polyurethane	Brown
30	Discarded tire	SBR	Polyurethane	Green
31	Discarded tire	SBR	–	Black
32[b]	Discarded tire	SBR	–	Black
33	Discarded tire	SBR, NR	–	Black
34[b]	Discarded tire	NR, SBR	–	Black
35	Discarded tire	NR, SBR	–	Black
36	Discarded tire	NR, SBR	–	Black
37	Synthetic rubber	EPDM	–	Beige
38	Thermoplastic elastomer	TPE	–	Green
39	Industrial rubber	NR, EP, NBR	–	Black
40	Discarded tire	NR	–	Black
41	Discarded tire	SBR, BR, NR	–	Black
42	Discarded tire	SBR	–	Black
43[b]	Industrial rubber	NR, SBR, EPDM	–	Black
44	Discarded tire	SBR, NR	–	Black
45	Discarded tire	SBR, NR	–	Black
46	Mixture/unknown	SBR	–	Black

[a] SBR: styrene-butadiene rubber, EPDM: ethylene-propylene-diene rubber, NR: natural rubber, BR: butadiene rubber, NBR: acrylonitrile butadiene rubber, TPE: thermoplastic elastomers. Material information was provided by the sample supplier.
[b] Samples used for elution test.
[c] Synthetic rubber of unknown type.

The first fluid was prepared by adding hydrochloric acid (7 mL) to sodium chloride (2.0 g) and adjusting it to a volume of 1 L (final pH 1.2) with water. The second fluid was prepared by dissolving potassium dihydrogen phosphate (3.40 g) and anhydrous disodium hydrogen phosphate (3.55 g) in water to a volume of 1 L, followed by mixing with an equal volume of water (final pH 6.8). The simulated saliva was prepared by dissolving sodium chloride (4.5 g), potassium chloride (0.3 g), sodium sulfate (0.3 g), ammonium chloride (0.4 g), urea (0.2 g), and L(+)-lactic acid (0.2 g) in water, and adjusting to pH 6.5–7.0 using 5 mol/L sodium hydroxide, and to a total volume of 1 L with water before use. The simulated perspiration of acid sweats was prepared by dissolving L-histidine monohydrochloride (0.5 g), sodium chloride (5 g), and sodium dihydrogen phosphate (1.91 g) in water, adding 15 mL of 0.1 mol/L sodium hydroxide aqueous solution, and adjusting to a total volume of 1 L with water before use (final pH 5.5).

The substances used for elution testing were pesticide analysis-grade sodium chloride, reagent-grade potassium dihydrogen phosphate, anhydrous disodium hydrogen phosphate, potassium chloride, ammonium chloride, urea, L-histidine monohydrochloride monohydrate, and anhydrous sodium dihydrogen phosphate (Kanto Chemical Co. and Wako Pure Chemical Industries). All the chemicals were of reagent grade. Anhydrous sodium sulfate (Merck Sigma-Aldrich, St. Louis, MO, USA), L(+)-lactic acid (Acros Organics, Geel, Belgium), hydrochloric acid (harmful metal analysis grade), and sodium hydroxide aqueous solution (5 mol/L; volumetric analysis grade) (Wako Pure Chemical Industries) were also used. The sodium hydroxide aqueous solution was diluted with water to produce a 0.1 mol/L aqueous solution.

2.4. Analytical methods

Two analytical methods were employed. Method 1 was applied to all samples except Sample No. 39. This sample contained a large amount of plastic plasticizers, so some compounds could not be analyzed by Method 1. Therefore, Method 2 was applied to Sample No. 39.

2.4.1. Method 1

The sample was extracted by modifying the PAH analysis procedure used for product safety certification (GS mark) (Ausschuss für Produktsicherheit, AfPS, 2014), which is based on the German Product and Equipment Safety Act.

Variations in extraction efficiency with ultrasonic extraction time and extraction behavior with and without coating were investigated using No. 18 and No. 20. We performed ultrasonic extraction from each sample for 30, 60, and 120 min and compared the total amounts of the extracted target substances.

Based on the results of the extraction time study, Method 1 was as follows. Five milliliters of toluene and 250 μL of internal standard (10 μg/mL of toluene solution) were added to 0.5 g of sample in a headspace vial, and the vial was closed with a septum-bearing crimp cap. Extraction was performed for 60 min at 60 °C using an ultrasonicator (UT-105HS; Sharp Manufacturing Systems Inc., Yao, Japan). After removal from the ultrasonicator, the sample was cooled before filtering through a 0.20 μm polytetrafluoroethylene membrane filter (GL Chromatodisk, GL Sciences). The eluate was then analyzed using gas chromatography–mass spectrometry (GC–MS). All experiments were performed in triplicate.

In addition, to ensure that there is no loss of analytes in the course of the analytical operation, 5 mL of toluene with 250 μL of a mixed standard solution containing 5 μg/mL of all measured target substances was added was analyzed by the above method.

2.4.2. Method 2

The sample (0.5 g) was placed in a 50 mL centrifuge tube, 10 mL of acetone and 250 μL of a toluene solution containing 10 μg/mL of the internal standard were added, the lid was closed, and ultrasonic extraction was performed for 30 min before transferring the extract to a separate centrifuge tube. Subsequently, 10 mL of hexane was added to the residue, which was then subjected to ultrasonic extraction for 30 min. Then, 5 mL of 1 mol/L potassium hydroxide-ethanol solution was added to the acetone extract and alkali decomposition was performed for 30 min. Next, 10 mL of ultrapure water was added to the residual hexane extract and the sample was shaken for 10 min, followed by the transfer of the hexane phase to a flask. Hexane (10 mL) was added to the water phase again, followed by 10 min of shaking, and the hexane phase was transferred to the flask. After reducing the volume of the hexane in the flask to 5–10 mL in a rotary evaporator and then to approximately 0.5 mL under a nitrogen gas stream, the extract was brought to a volume of 5 mL by adding toluene. The test was performed in triplicate.

Similar to Method 1, an experiment was conducted in which a standard substance was added to the extraction solvent to check for any loss of the analyte during the analysis process. In addition, to compare the extraction efficiency with that of Method 1, sample No. 1 was analyzed by both Methods 1 and 2, and the results were compared.

Table 2
PAHs and related chemicals investigated in this study.

Chemicals	Abbreviation	CASRN[a]	PAH[b]	Boiling point (°C)[c]	logPow[c]	Supplier[d]	Mixed standard solution[e]
Naphthalene	NAP	91-20-3	✓	218	3.30	ACC	○
2-Methylnaphthalene	2-MNAP	91-57-6		241	3.86	ACC	
1-Methylnaphthalene	1-MNAP	90-12-0		245	3.87	Wako	
Biphenyl	BPh	92-52-4		256	4.01	Kanto	
2,6-Dimethylnaphthalene	2,6-DMNA	581-42-0		262	4.31	TCI	
Acenaphthylene	AcPY	208-96-8	✓	280	3.94	ACC	○
Acenaphthene	AcPH	83-32-9	✓	279	3.92	ACC	○
Dibenzofuran	DF	132-64-9		287	4.12	ACC	
Fluorene	FL	86-73-7	✓	295	4.18	ACC	○
Dibenzothiophene	DTh	132-65-0		333	4.38	TCI	
Phenanthrene	Phe	85-01-8	✓	340	4.46	ACC	○
Anthracene	Anth	120-12-7	✓	340	4.45	ACC	○
3-Methylphenanthrene	3-MPhe	832-71-3		350	5.15	TCI	
Carbazole	Carb	86-74-8		355	3.72	ACC	
2-Methylphenanthrene	2-MPhe	2531-84-2		–[f]	4.86	ACC	
9-Methylphenanthrene	9-MPhe	883-20-5		–	5.30	CA	
1-Methylphenanthrene	1-MPhe	832-69-9		–	5.08	ACC	
Fluoranthene	FLA	206-44-0	✓	384	5.16	ACC	○
Pyrene	PYR	129-00-0	✓	404	4.88	ACC	○
Benzo[*c*]fluorene	BcFL	205-12-9	✓	–	5.70	DEN	
Benzo[*c*]phenanthrene	BcPhe	195-19-7	✓	–	5.70	ACC	○
Benz[*a*]anthracene	BaA	56-55-3	✓	438	5.76	ACC	○
Cyclopenta[*cd*]pyrene	CcdP	27208-37-3	✓	–	5.50	ACC	
Triphenylene	TRP	217-59-4	✓	425	5.49	TCI	
Chrysene	CHR	218-01-9	✓	448	5.81	ACC	○
5-Methylchrysene	5-MCHR	3697-24-3		–	6.07	ACC	
Benzo[*b*]fluoranthene	BbFLA	205-99-2	✓	481	5.78	ACC	○
Benzo[*k*]fluoranthene	BkFLA	207-08-9	✓	480	6.11	ACC	○
7,12-Dimethylbenz[*a*]anthracene	7,12-DMBaA	57-97-6		–	5.80	TCI	○
Benzo[*j*]fluoranthene	BjFLA	205-82-3	✓	–	6.11	ACC	○
Benz[*j*]aceanthrylene/Benz[e]aceanthrylene[g]	BjAA/BeAA	202-33-5/199-54-2	✓	–	6.20/6.20	CS	
Benzo[*e*]pyrene	BeP	192-97-2	✓	492	6.44	ACC	○
Benzo[*a*]pyrene	BaP	50-32-8	✓	495	6.13	ACC	○
3-Methylcholanthrene	3-McAnth	56-49-5		280 (80 mmHg)	6.42	Merck	○
Dibenz[*c*,*h*]acridine	DchAc	224-53-3		–	6.45	Merck	
Dibenz[*a*,*h*]acridine	DahAc	226-36-8		–	5.73	Merck	
Dibenz[*a*,*j*]acridine	DajAc	224-42-0		–	5.63	ACC	
Indeno[1,2,3-*cd*]pyrene	IcdPYR	193-39-5	✓	536	6.70	ACC	○
Dibenz[*a*,*h*]anthracene	DahAnth	53-70-3	✓	524	6.75	ACC	○
Benzo[*ghi*]perylene	BghiPl	191-24-2	✓	550	6.63	ACC	○
7H-Dibenzo[*c*,*g*]carbazole	7H-DcgCarb	194-59-2		–	5.90	TCI	
Dibenzo[*a*,*l*]pyrene	DalPYR	191-30-0	✓	631	7.71	TCI	○
Dibenzo[*a*,*e*]pyrene	DaePYR	192-65-4	✓	–	7.28	ACC	
Coronene	Coro	191-07-1	✓	525	7.64	TCI	
Dibenzo[*a*,*i*]pyrene	DaiPYR	189-55-9	✓	275 (0.05 mmHg)	7.28	ACC	○
Dibenzo[*a*,*h*]pyrene	DahPYR	189-64-0	✓	–	7.28	TCI	○

[a] Chemical abstract service registry number.
[b] Compounds belonging to PAHs are marked with ✓.
[c] Cited from PubChem (https://pubchem.ncbi.nlm.nih.gov/). logKow: Octanol water partition coefficient.
[d] ACC: AccuStandard, Inc., Wako: FUJIFILM Wako Pure Chemical Corporation, Kanto: Kanto Chemical Co., Inc., TCI: Tokyo Chemical Industry Co., Ltd., CA: Chiron AS, DEN: Dr. Ehrenstorfer GmbH, CS: Carbosynth Ltd., Merck: Merck KGaA.
[e] Quebec Ministry of Environ.PAH MIX) (500 μg/mL in dichloromethane:benzene).
[f] No data.
[g] Benz[*j*]aceanthrylene/benz[*e*]aceanthrylene ratio was 7/3.

2.5. Elution testing

Eight samples were selected for the elution tests (numbers 2, 8, 23, 28, 29, 32, 34, and 43 in Table 1) owing to the carcinogenicity of the detected compounds and their contents. All eight samples originated from discarded tires or industrial rubber. The elution tests were conducted according to the EPA research protocol (USEPA, 2016b), which involves placing a rubber infill sample (1.0 g) in a screw-cap Erlenmeyer flask with the elution test solution (50 mL). The elution of PAHs and related compounds was allowed to occur by incubation in a dark environment for 1 h at 37 °C with shaking at 30 rpm, and the eluate was filtered through a glass-fiber filter (Whatman GF/F; 0.7 μm pore size). Then, 5 mL of hexane was added to 10 mL of filtrate, and after shaking for 15 min, the solvent phase was fractionated via centrifugal separation for 15 min. This process was performed twice, and the obtained solvent phases were combined. The combined solvent phases were dehydrated using anhydrous sodium sulfate and filtered. Then, 10 μL of hexane containing 1000 μg/mL of diethylene glycol was added, and this solution was then concentrated to 1 mL or less under a nitrogen gas stream and brought to a volume of 5 mL with toluene, followed by the addition and thorough mixing of 250 μL of a toluene solution containing 10 μg/mL of the internal standard. Subsequently, the resultant sample was analyzed using GC–MS. All experiments were performed in triplicate.

2.6. Analytical instrument conditions

The GC–MS analyses were performed using a 7980 B GC system with a 5977 B MSD (Agilent Technologies, Santa Clara, CA, USA), and quantification was performed using the selected ion monitoring mode; information about the other analytical conditions is provided in the Supporting Information. Table S1 lists the retention times and quantitative and qualitative

characteristics of the ions in the compounds determined via GC–MS. Some target PAHs contained isomers with nearly equal mass spectra, which were difficult to qualify. In such cases, qualitative confirmation was performed using several types of GC columns.

For each series of analyses, calibration cures were prepared using standard solutions. The correlation coefficient for each calibration curve was confirmed to be >0.99 for all analytes. In addition, blank tests were performed for each analytical batch to confirm that there was no contamination of the analytes derived from the analytical operation.

2.7. Statistical analysis

EZR software was used for statistical analysis (Kanda, 2013). The Mann–Whitney *U* test was performed to compare the differences in compound concentrations between the origins of each test material. A *p*-value <0.05 was assumed to be statistically significant in all EZR data statistical analyses.

3. Results and discussion

3.1. Investigation of extraction conditions (content analysis)

3.1.1. Method 1

In the present study, the analytical method using ultrasonic extraction with toluene described by AfPS (2016) was employed. A similar analytical method was used by Grynkiewicz–Bylina et al. (2022) to study rubber infills. Llompart et al. (2013) also reported no difference in extraction efficiency between ultrasonic extraction and fast solvent extraction, although the solvent was ethyl acetate. Using the same method as that used by Llompart et al. (2013), Armada et al. (2022) also analyzed rubber infills from around the world. Therefore, it was assumed that analysis by the method used in this study would provide data that could be compared with the results of the analysis of other rubber infills.

Prior to the analysis of the rubber infills, the time of ultrasonic extraction was studied (Fig. S1). No significant difference in ultrasonic extraction time was observed between the samples with and without coating; however, the level of extraction after 30 min tended to be rather low, and therefore an extraction time of 60 min was adopted.

In addition, experiments were conducted to confirm that there was no loss of analytes in the process of analytical operations. The recovery rates in this experiment are listed in Table S2. For all substances, the recovery rate was >92 % and the coefficient of variation was <2 %.

3.1.2. Method 2

The presence of an interfering substance in one sample of industrial rubber (Sample No. 39) prevented the use of Method 1 to measure benzo[*c*]fluorene, benzo[*c*]phenanthrene, benzo[*a*]anthracene, cyclopenta[*cd*]pyrene, triphenylene, chrysene, 5-methylchrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, 7,12-dimethylbenz[*a*]anthracene, and benzo[*j*]fluoranthene. Analysis of Sample No. 39 using GC–MS revealed an extremely large peak for an interfering substance at retention times of 18.5 and 20.5 min; this peak was attributed to the compound that prevented the measurement of these substances (Fig. S2). Based on the NIST library, this peak exhibited the greatest similarity with di-(2-ethylhexyl) isophthalate (DEHIP CASRN: 137-89-3) (Fig. S2).

Although only one such sample was observed, no missing measurements were allowed to ensure the safety of athletes, other players, and children. Thus, we considered this interfering substance to be DEHIP and studied its removal method. As an ester, DEHIP undergoes hydrolysis under basic pH conditions; in contrast, none of the substances to be measured decomposed under such conditions. Therefore, 1 mol/L potassium hydroxide-ethanol solution was added to the sample extraction solution to decompose and remove DEHIP. When the sample solution was pretreated using this method, the intensity of the peak corresponding to the interfering substance decreased (Fig. S2), enabling analysis of the substances that were impossible to measure using Method 1. Therefore, we applied Method 2 to measure the concentrations in Sample No. 39, which could not be measured using Method 1.

As in Method 1, experiments were conducted to confirm that there was no loss of analytes during the analytical operations, and the recovery rates are shown in Table S2. In addition, to compare the extraction efficiency with Method 1, Sample No. 1 was analyzed by both Methods 1 and 2. The extraction efficiency of Method 2, which was evaluated using Sample No. 1, was 72.7 %–107.8 %. The extraction efficiencies of benzo[*c*]fluorene, benzo[*c*]phenanthrene, 5-methylchrysene, and 7,12-dimethylbenz[*a*]anthracene were not evaluated because these compounds were not detected in Sample No. 1.

3.2. Investigation of extraction conditions (elution testing)

To measure the recovery rates, 0.05 μg of each compound was added to 10 mL of simulated biofluid; all compounds exhibited good recovery rates of 71 %–117 % with variation coefficients of 0.59 %–13 % (Table S3). The limit of quantification (LOQ) of the elution tests of all measured compounds was set at 0.025 μg/g. At this value, all compound peaks were detectable at signal/noise ratio > 10.

3.3. PAH concentrations in rubber granule

Table 3 presents the analytical results of the samples classified according to their origin. Except for one sample, PAHs or similar substances were negligible in the samples derived from the synthetic rubber and thermoplastic elastomers. The samples derived from synthetic rubber contained only EPDM, and those derived from thermoplastic elastomers contained only TPE; therefore, both presumably contained negligible quantities of PAHs. A relatively high PAH content was detected in one of the samples derived from thermoplastic elastomers. As this sample was unused, any PAHs detected were assumed to be formed as a result of the manufacturing processes.

Various PAHs were detected in the 37 samples derived from discarded tires, industrial rubber, and mixture or unknown categories. Of the 46 PAHs assayed, 32 were identified in this study. Among the detected PAHs, benzo[*a*]pyrene, which is classified as IARC Group 1 (recognized carcinogen), was detected in all 37 samples in the category containing discarded tires, industrial rubber, and mixture or unknown products. Cyclopenta[*cd*]pyrene, classified as Group 2A (probably carcinogenic), was also detected in all 37 samples.

A comparison of the total concentrations of 32 detected compounds indicated a slightly higher concentration in discarded tires than in industrial rubber (Mann–Whitney *U* test, $^{**}p < 0.01$) (Fig. 1). Among the PAHs, cyclopenta[*cd*]pyrene and benzo[*a*]pyrene concentrations were also higher in discarded tires than in industrial rubber (Fig. 2). Several industrial rubber samples contained admixed EPDM; however, none of the samples derived from discarded tires contained any EPDM admixture (Table 1). As described above, EPDM contained negligible amounts of PAHs, and the comparatively low concentrations of PAHs detected in the industrial rubber can be attributed to the admixture of EPDM. Among the measured PAHs, comparatively high concentrations of volatile naphthalene, 1-methylnaphthalene, and others were found in industrial rubber (Fig. 2). Naphthalene and 1-methylnaphthalene are compounds with lower boiling points and higher water solubility than other PAHs (Table 2). Li et al. (2010) reported that naphthalene and 1-mehtyl naphthalene were released into the gas phase from crumb rubber material. Celeiro et al. (2018) also reported that PAHs leach from rubber infills into water or are released into the gas phase. Unlike industrial rubber, discarded tire samples have been used as tires for a period. It was considered possible that naphthalene and 1-methylnaphthalene were released into the gas phase or leached into water during this period.

The maximum PAH concentrations observed in the present study were either similar to or lower than those observed in other studies (ECHA, 2017; Gomes et al., 2010; Li et al., 2010; Llompart et al., 2013; Marsili et al., 2015; Menichini et al., 2011; RIVM, 2017; Schneider et al., 2020a). To assess

Table 3
Concentrations of compounds detected and their detection frequencies.[a]

			NAP	2-MNAP	1-MNAP	BPh	2,6-DMNA	AcPY	AcPH	DF	FL	DTh	Phe	Anth	3-MPhe	2-MPhe	9-MPhe	1-MPhe
Dicarded tire	Concentration(μg/g)	Min	0.438	0.132	0.119	0.0775	0.159	0.386	0.081	0.153	0.0892	0.145	2.21	0.155	0.123	0.178	0.0866	0.0693
24 products		Max	1.33	0.337	0.295	0.267	0.348	1.79	0.208	0.269	0.422	0.379	4.50	0.661	1.52	1.90	1.02	1.01
72 samples		Average	0.875	0.240	0.218	0.126	0.248	1.04	0.126	0.196	0.151	0.223	3.22	0.271	0.368	0.487	0.317	0.265
		Median	0.892	0.221	0.223	0.118	0.243	1.03	0.123	0.193	0.123	0.206	3.15	0.238	0.244	0.329	0.219	0.165
	Standard deviation		0.205	0.0581	0.0503	0.0415	0.0557	0.357	0.0350	0.0285	0.0840	0.0638	0.545	0.121	0.350	0.426	0.277	0.256
	Detection number		24	24	24	24	24	24	23	24	24	24	24	24	24	24	24	24
	Detection frequency (%)		100	100	100	100	100	100	95.8	100	100	100	100	100	100	100	100	100
Industrial rubber	Concentration (μg/g)	Min	0.209	0.196	0.117	0.0625	0.11	0.143	0.0679	0.0555	0.0261	0.0642	0.907	0.128	0.0519	0.0606	0.0693	0.0562
1 product		Max	6.95	3.33	1.91	0.703	3.14	0.946	0.192	0.817	0.36	0.91	3.47	0.456	4.29	1.28	0.998	0.857
3 samples		Average	1.59	0.835	0.622	0.260	0.775	0.517	0.111	0.317	0.199	0.332	1.74	0.246	0.725	0.384	0.353	0.265
		Median	0.935	0.534	0.405	0.187	0.469	0.544	0.0864	0.194	0.159	0.214	1.54	0.235	0.208	0.245	0.223	0.162
	Standard deviation		2.03	0.934	0.575	0.213	0.894	0.281	0.0492	0.274	0.128	0.295	0.767	0.110	1.30	0.378	0.343	0.300
	Detection number		10	10	10	10	10	10	6	10	8	7	10	7	10	10	6	6
	Detection frequency (%)		100	100	100	100	100	100	60	100	80	70	100	70	100	100	60	60
Mixture/unknown	Concentration (μg/g)	Min	0.540	0.288	0.190	0.0885	0.259	0.298	0.0940	0.189	0.133	0.247	3.11	0.221	0.292	0.378	0.316	0.238
3 products		Max	1.42	0.427	0.381	0.264	0.52	1.05	0.439	0.263	0.705	0.870	3.33	0.514	1.15	1.34	1.81	1.36
9 samples		Average	0.919	0.341	0.268	0.169	0.353	0.668	0.214	0.214	0.328	0.470	3.24	0.320	0.586	0.726	0.830	0.625
		Median	0.792	0.307	0.231	0.154	0.280	0.651	0.111	0.191	0.146	0.291	3.28	0.226	0.320	0.460	0.364	0.274
	Standard deviation		0.455	0.0752	0.100	0.0889	0.145	0.379	0.195	0.0424	0.326	0.348	0.116	0.168	0.485	0.533	0.849	0.640
	Detection number		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Detection frequency (%)		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Synthetic rubber	Concentration (μg/g)	Min	0.0361	0.105	0.0233	0.0292	0.0559			0.0515	0.0376		0.0261					
5 products		Max	0.267	0.105	0.0630	0.0292	0.0559			0.0515	0.0376		0.0455					
15 samples		Average	0.138	0.105	0.0432	0.0292	0.0559			0.0515	0.0376		0.0363					
		Median	0.124	0.105	0.0432	0.0292	0.0559			0.0515	0.0376		0.0371					
	Standard deviation		0.113		0.0281								0.00971					
	Detection number		4	1	2	1	1			1	1		3					
	Detection frequency (%)		80	20	40	20	20			20	20		60					
Thermoplastic elastomers	Concentration (μg/g)	Min	0.509	0.43	0.416		0.567			0.664			0.395		0.457	0.605	1.15	0.579
4 products		Max	0.509	0.43	0.416		0.567			0.664			0.395		0.457	0.605	1.15	0.579
12 samples		Average	0.509	0.43	0.416		0.567			0.664			0.395		0.457	0.605	1.15	0.579
		Median	0.509	0.43	0.416		0.567			0.664			0.395		0.457	0.605	1.15	0.579
	Standard deviation																	
	Detection number		1	1	1		1			1			1		1	1	1	1
	Detection frequency (%)		25	25	25		25			25			25		25	25	25	25

			FLA	PYR	BcFL	BaA	CcdP	TRP	CHR	BbFLA	BkFLA	BjFLA	BeP	BaP	IcdPYR	DahAnth	BghiPl	Coro	Σ8 REACH PAHs[b]
Dicarded tire	Concentration (μg/g)	Min	6.43	19.8	0.0229	0.0406	1.83	0.0799	0.0775	0.137	0.0484	0.0671	1.29	0.566	0.224	0.317	2.02	0.590	
24 products		Max	12.0	35.5	0.297	2.23	6.19	2.26	3.13	0.907	0.348	0.340	4.60	2.84	1.35	0.317	9.60	8.45	14.7
72 samples		Average	9.30	29.2	0.134	0.322	3.31	0.494	0.554	0.407	0.134	0.165	2.32	1.36	0.725	0.317	4.47	1.88	
		Median	9.48	30.2	0.133	0.121	3.30	0.276	0.293	0.373	0.115	0.162	2.21	1.30	0.707	0.317	4.30	1.31	
	Standard deviation		1.32	4.17	0.102	0.511	0.887	0.563	0.725	0.161	0.0683	0.0582	0.728	0.481	0.245		1.60	1.83	
	Detection number		24	24	6	24	24	24	24	24	24	24	24	24	24	1	24	24	
	Detection frequency (%)		100	100	25	100	100	100	100	100	100	100	100	100	100	4.17	100	100	
Industrial rubber	Concentration (μg/g)	Min	2.12	9.55	0.2	0.0369	0.413	0.0678	0.0765	0.0372	0.0447	0.0440	0.899	0.415	0.353	0.0682	2.88	0.971	
1 product		Max	8.71	32.1	0.2	1.48	4.94	2.88	2.11	1.09	0.402	0.476	3.1	1.98	0.808	0.789	6.59	2.99	11.4
3 samples		Average	4.82	19.7	0.2	0.298	1.87	0.792	0.434	0.500	0.147	0.138	1.85	0.997	0.621	0.309	3.98	1.63	
		Median	4.52	19.8	0.2	0.0613	1.44	0.250	0.292	0.383	0.104	0.118	1.64	0.951	0.659	0.07	3.90	1.31	
	Standard deviation		2.18	7.42		0.581	1.34	0.991	0.600	0.332	0.116	0.123	0.758	0.391	0.167	0.416	1.06	0.779	
	Detection number		10	10	1	6	10	10	10	9	9	10	10	10	10	3	10	10	
	Detection frequency (%)		100	100	10	60	100	100	100	90	90	100	100	100	100	30	100	100	
Mixture/unknown	Concentration (μg/g)	Min	5.01	12.6	0.0472	0.116	0.521	0.312	0.278	0.479	0.146	0.176	2.43	1.52	0.815		2.31	0.613	
3 products		Max	11.7	37.4	0.136	1.31	3.07	1.16	1.7	1.52	0.578	0.583	3.07	1.86	0.933		4.91	1.49	10.6
9 samples		Average	9.19	28.3	0.0916	0.538	2.20	0.645	0.825	0.832	0.290	0.320	2.68	1.65	0.864		3.87	1.09	
		Median	10.9	34.8	0.0472	0.190	3.00	0.457	0.500	0.500	0.146	0.201	2.53	1.58	0.842		4.38	1.17	
	Standard deviation		3.64	13.6	0.0627	0.668	1.45	0.456	0.763	0.593	0.249	0.228	0.347	0.18	0.0618		1.37	0.441	
	Detection number		3	3	2	3	3	3	3	3	3	3	3	3	3		3	3	
	Detection frequency (%)		100	100	66.7	100	100	100	100	100	100	100	100	100	100		100	100	
Synthetic rubber	Concentration (μg/g)	Min		0.0216															
5 products		Max		0.0216															0
15 samples		Average		0.0216															
		Median		0.0216															
	Standard deviation																		
	Detection number			1															
	Detection frequency (%)			20															
Thermoplastic	Concentration (μg/g)	Min							0.229										
elastomer		Max							0.229										0.299
4 products		Average							0.229										
12 samples		Median							0.229										
	Standard deviation																		
	Detection number								1										
	Detection frequency (%)								25										

[a] Each product was measured at triplicate, and the number of samples was three times the number of products, and non-detects were treated as zero and not counted.

[b] Sum of the maximum values of eight REACH PAHs.

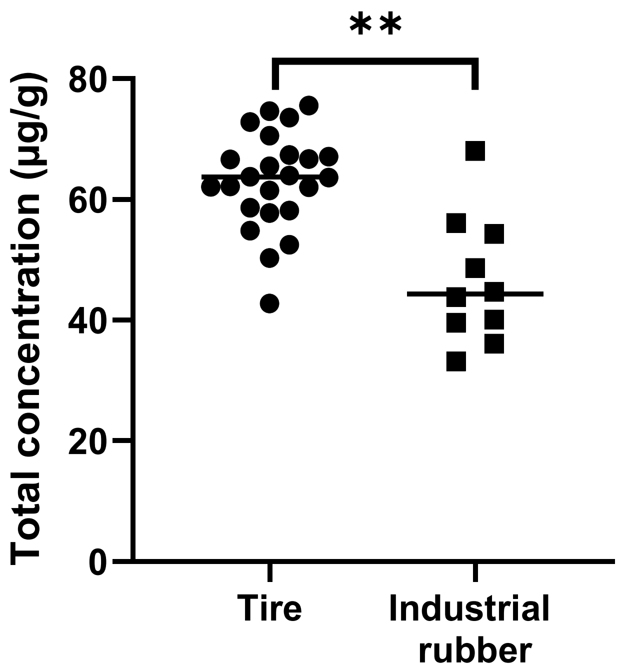

Fig. 1. Total concentration of 32 detected compounds extracted from rubber infill samples composed of tire and industrial rubber (Mann–Whitney *U* test, **: $p < 0.01$).

the health risks posed by PAHs, the ECHA used a total concentration of 20 µg/g for eight common PAHs (benzo[*a*]pyrene, benzo[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, dibenzo[*a*,*h*]anthracene, benzo[*j*]fluoranthene, and benzo[*a*]pyrene) (ECHA, 2017); based on that risk assessment, it was concluded that the health risk owing to PAHs was low. Furthermore, the European Union will restrict the sum of these eight PAH concentrations in rubber granulate used as infill material to a maximum of 20 mg/kg (European Union, 2021). Following a worldwide study in which rubber granules from 91 fields in 17 countries (four continents) were collected and examined, the concentrations of eight PAHs were reported to exceed 20 mg/kg in three samples (Armada et al., 2022). In contrast, in this study, based on the highest PAH concentrations, the total concentration of the same eight REACH PAHs as those in the ECHA report was calculated to be 14.7 µg/g for the discarded tire samples, 11.4 µg/g for the industrial rubber samples, and 10.6 µg/g for the mixture/unknown samples, lower than the ECHA risk assessment and limitation value. As the rubber infill samples employed in this study accounted for 95 % of the Japanese market share, it is highly unlikely that Japanese artificial turf fields use rubber infills containing PAHs that exceed the limits of the REACH regulation.

3.4. Elution testing

The PAH concentrations in the rubber infill samples used for the elution test are shown in Fig. 3. In this study, for all PAHs and their related compounds, the elution amount was lower than the LOQ (0.025 µg/g). In a

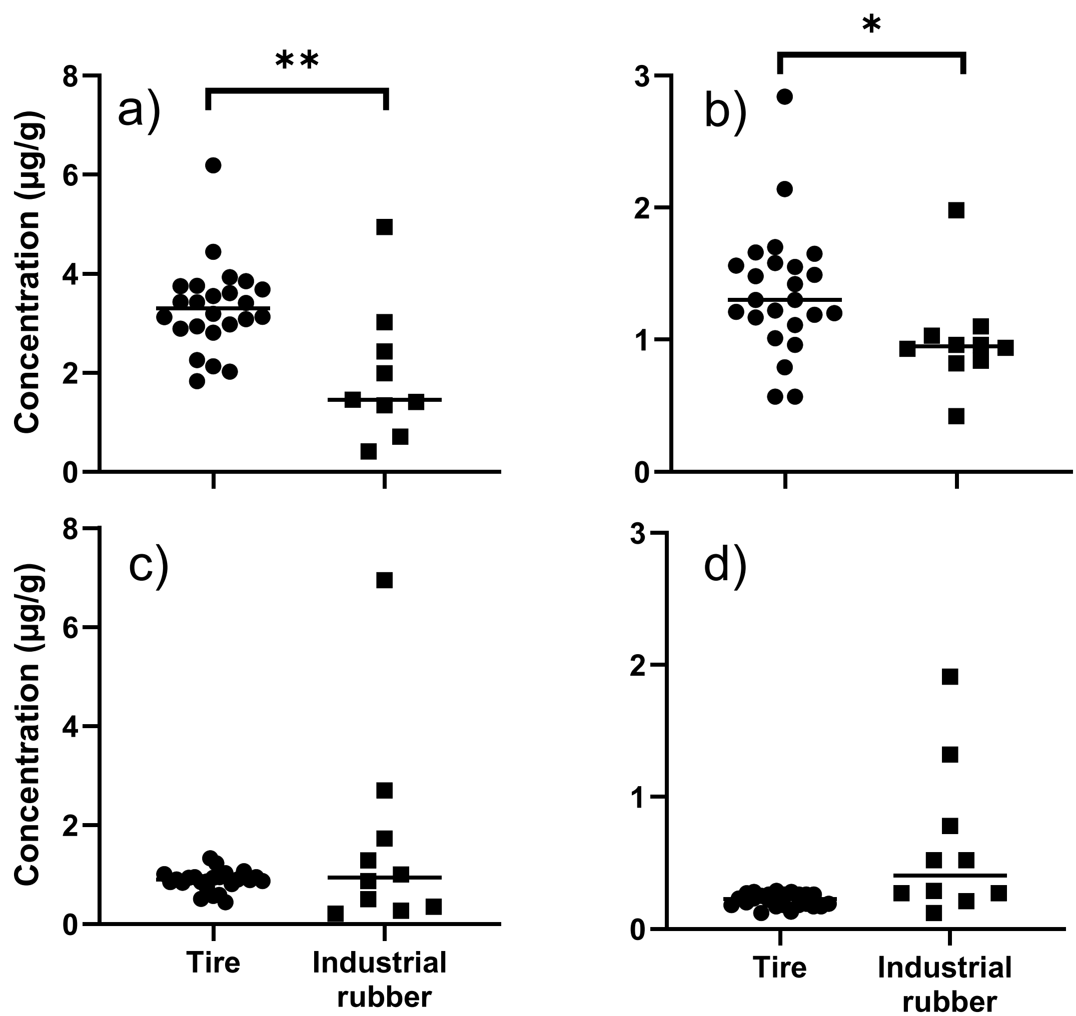

Fig. 2. Concentrations of (a) cyclopenta[*cd*]pyrene, (b) benzo[*a*]pyrene, (c) naphthalene, and (d) 1-methylnaphthalene extracted from rubber infill samples composed of tire and industrial rubber. (Mann–Whitney *U* test, *: $p < 0.05$, **: $p < 0.01$).

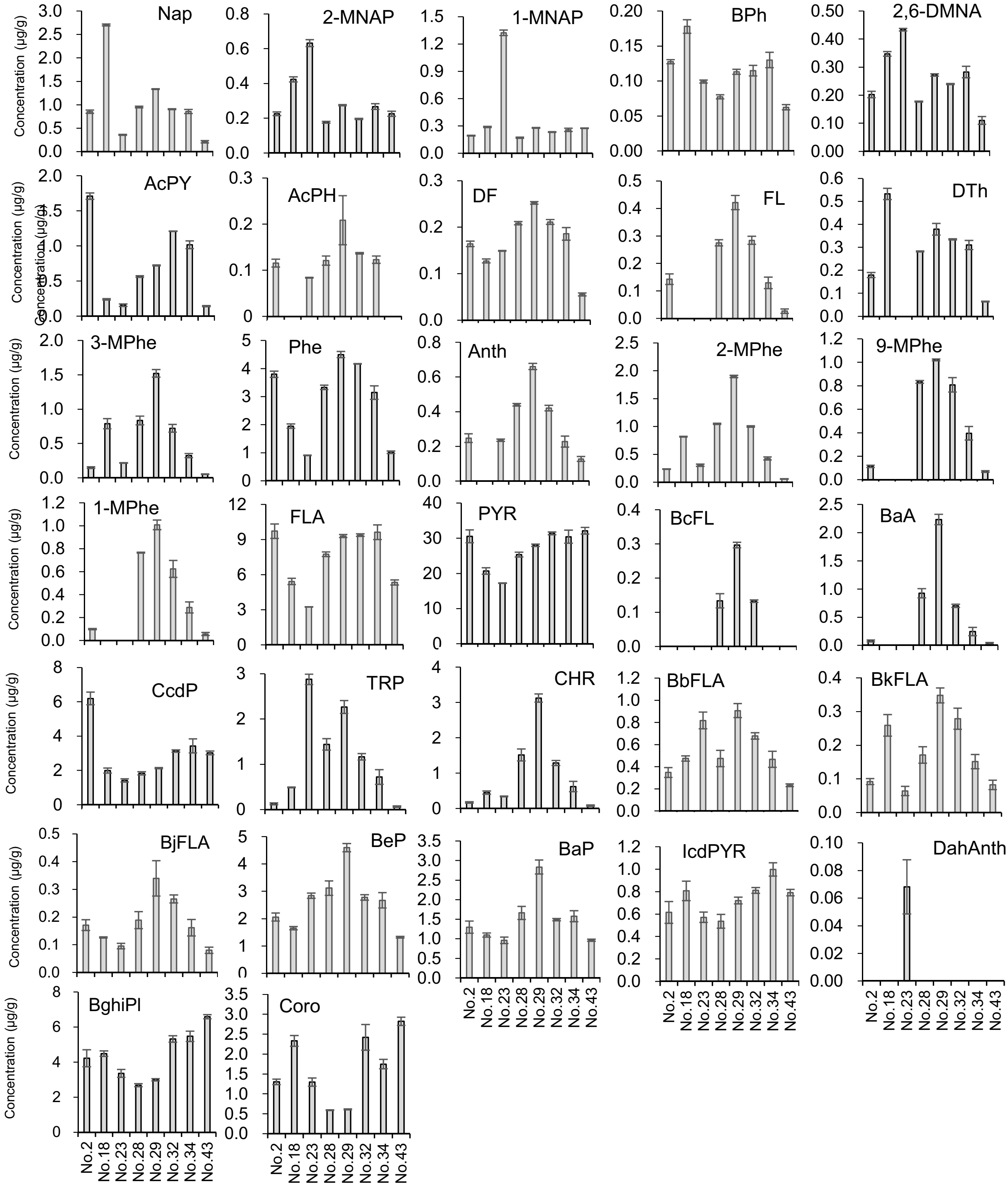

Fig. 3. Concentrations of chemicals in rubber infill samples used for elution test. (Average ± standard deviation).

previous study, an elution test was conducted using artificial sweat. Among the eight REACH PAHs regulated by EU, only chrysene was detected in artificial sweat, and the detected quantity was very low (Schneider et al., 2020b). In another study, elution tests were performed using artificial sweat and gastro-intestinal juices, and the eluted amounts of PAHs were also very low (RIVM, 2017). The PAH concentration in the rubber infill used in this study was lower than the REACH regulation limit and was relatively low. Therefore, it was considered that no PAHs above the LOQ were detected when the elution tests were performed.

The elution rates of the chemicals were calculated using the following equation: elution rate (%) = 100 × Ae/Cr, where Ae is the amount of the chemical eluted in the elution testing solution (μg/g) and Cr is the concentration of the chemical in the rubber infill sample (μg/g). In this study, the LOQ was taken as Ae. The estimated maximum elution amount from rubber infill was calculated using the maximum elution rate and maximum concentration in the rubber infills obtained in this study, considering the worst case (Table 4). For fluorene, the obtained elution-test LOQ was greater than the actual fluorene content of the sample employed in the elution test; thus, 100 % elution was assumed for fluorene. This characteristic occurred because of the low content of fluorene in the rubber infills utilized for the elution test. The estimated maximum elution amount in each biofluid will be used for the subsequent risk assessment study.

Table 4
Estimated maximum elution amounts of PAHs and related compounds calculated from elution test results.

Chemicals	Maximum elution late (%)[a]	Maximum concentration (μg/g)[b]	Estimated maximum elution amount (μg/g)
NAP	12.9	6.95	0.896
2-MNAP	14.4	3.33	0.481
1-MNAP	15.1	1.91	0.289
BPh	41.8	0.703	0.294
2,6-DMNA	26.1	3.14	0.821
AcPY	18.3	1.79	0.327
AcPH	30.0	0.439	0.132
DF	48.1	0.817	0.393
FL	100[c]	0.705	0.705
DTh	40.0	0.910	0.364
Phe	2.78	4.50	0.125
Anth	21.8	0.661	0.144
3-MPhe	50.4	4.29	2.16
2-MPhe	43.8	1.90	0.832
9-MPhe	38.4	1.81	0.696
1-MPhe	52.5	1.36	0.715
FLA	0.774	12.0	0.0927
PYR	0.145	37.4	0.0543
BcFL	22.7	0.297	0.0674
BaA	87.7	2.23	1.96
CcdP	1.90	6.19	0.118
TRP	46.5	2.88	1.34
CHR	39.4	3.13	1.23
BbFLA	11.3	1.52	0.171
BkFLA	46.9	0.578	0.271
BjFLA	34.0	0.583	0.199
BeP	1.94	4.60	0.0892
BaP	2.87	2.84	0.0815
IcdPYR	5.34	1.35	0.0720
DahAnth	54.4	0.789	0.429
BghiPl	0.967	9.60	0.0929
Coro	4.31	8.45	0.364

[a] All elution tests yielded results below the LOQ (0.025 μg/g). The LOQ was calculated as the maximum elution (same value for all four biofluids).
[b] Maximum value of 46 samples analyzed in this study.
[c] The LOQ concentration in the elution test exceeded the sample concentration (0.017 μg/g). The dissolution rate was assumed to be 100 %.

4. Conclusions

In this study, we analyzed the actual contents of 46 PAHs and related compounds in domestically distributed rubber granules, which are widely used in synthetic turf for sports fields. The samples were extracted using a partially modified version of the PAH analysis method for German GS Mark certification. As a result, the investigated target substances were rarely found in samples consisting only of EPDM or TPE. However, in the samples derived from discarded tires and industrial rubber, IARC cancer-risk Group 1-classified benzo[*a*]pyrene, Group 2A-classified cyclopenta [*cd*]pyrene, and 30 other compounds (among the 46 compounds considered) were detected. Comparison between the two sample groups indicated higher concentrations of the target compounds in the discarded tire-derived samples than in the samples derived from industrial rubber. This finding can be attributed to the presence of EPDM in almost all of the industrial rubber-derived samples, whereas the same was detected in the samples derived from the discarded tires. The maximum PAH concentrations obtained in the present study were equivalent to or lower than the previously reported PAH concentrations. The total concentration of the eight PAHs used in the ECHA health risk assessment was lower in this study than that reported by the ECHA. As the rubber infill samples used in this study accounted for 95 % of the Japanese market share, it is highly unlikely that Japanese artificial turf fields use rubber infills containing PAHs that exceed the limits of the REACH regulation.

Elution testing was performed with four simulated biofluids (gastric and intestinal juices, saliva, and perspiration), and the obtained results were used to assess the exposure levels. Due to low concentrations in the rubber infills distributed in Japan, the actual elution amounts of all compounds were lower than the LOQ value (0.025 μg/g). Therefore, the LOQ was used to calculate the estimated maximum elution amount. This estimated maximum elution amount will be used in subsequent risk assessment studies.

CRediT authorship contribution statement

Iwaki Nishi, Tsuyoshi Kawakami: Conceptualization, methodology, investigation, writing-original draft. Shinobu Sakai, Reiji Kubota, Kaoru Inoue: Writing-review and editing. Tomoko Obama: investigation. Yoshiaki Ikarashi: Conceptualization, writing-review and editing, supervision, project administration, funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.156684.

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ERASSTRI - European risk assessment study on synthetic turf rubber infill – Part 3: Exposure and risk characterisation

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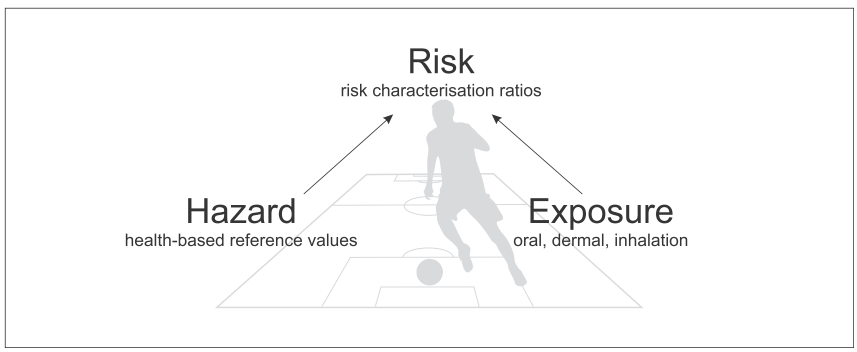
HIGHLIGHTS

- A comprehensive risk characterisation for substances in tyre granulate was performed.
- Cancer risks for exposure to PAHs were below 1 to 1 million.
- Risk characterisation ratios (RCRs) for non-carcinogenic substances were below 1.
- No health concerns were found for synthetic turfs with ELT-derived infill material.

GRAPHICAL ABSTRACT



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ABSTRACT

As the final part of a Europe-wide study on the risk from synthetic turf infill consisting of rubber granules derived from end-of-life tyres (ELT), exposure of sportspeople was assessed and compared with health-based reference values for various chemical substances. Based on information from previous project phases, exposure scenarios were established and exposure was calculated for oral, dermal and inhalation routes. Calculated cancer risks for exposure to polycyclic aromatic hydrocarbons were below 1:1 million. Risk characterisation ratios (RCRs) for non-carcinogenic substances were below 1, indicating no health concerns. For 2-hydroxybenzothiazole no toxicological data were found from which to derive a substance-specific reference value. A threshold-of-toxicological concern approach revealed maximum RCRs slightly above 1, which are acceptable, given the conservativism of the approach. ERASSTRI substantially improved the data available for assessing human health risks from using ELT-derived infill material. Overall, no health concerns could be identified for the use of synthetic turfs with ELT-derived infill material.

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1. Introduction

Concerns have been raised in recent years regarding the use of synthetic infill material from end-of-life tyres (ELT) in artificial turfs on sports fields. Synthetic turfs are widely used in Europe by amateur and professional sportspeople. ECHA (2017), based on data from the European Synthetic Turf Organisation, reported that there are over 13,000 large synthetic turf fields and an even higher number of mini-pitches in the European Union, mainly used for football, with numbers expected to increase in the coming years. One specific concern was a potential link between the use of synthetic turfs and the occurrence of leukaemia (Cheng et al., 2014; Watterson, 2017). Toxic substances such as polycyclic aromatic hydrocarbons (PAHs) or benzothiazole are known to be present in ELT-derived granules (Li et al., 2010; Ginsberg et al., 2011). However, recent risk assessments found no reasons for concern over the use of such artificial turfs, as the exposure was expected to be below critical levels (ECHA, 2017; RIVM, 2017a; Peterson et al., 2018; Pronk et al., 2018). The European Chemicals Agency (ECHA), which based their assessment on previously published data, found no significant health risks, but identified various limitations in the data. They noted that there might be additional critical substances not yet identified, that information on concentration of substances in tyre granulate is limited, and that several input values for estimating exposure are based on assumptions only (ECHA, 2017).

The European Risk Assessment Study on Synthetic Turf Rubber Infill (ERASSTRI) was launched by industrial associations and companies representing the tyre granulate supply chain (see Acknowledgements) to fill data gaps and provide comprehensive conclusions on potential health risks from using ELT granules in artificial turfs. This is the third and final publication reporting the results of this study. In a previous publication we provided information on chemical composition and volatiles released from ELT-derived rubber infill (Schneider et al., 2020b): 46 substances or substance groups were screened and their concentrations in the rubber matrix measured. Further, evaporation of volatile substances in emission chambers was measured. The second publication reported results of in vitro migration studies, where we determined the bioaccessibility of substances in artificial body fluids such as sweat or saliva simulants to support dermal and oral exposure assessment. Also, in this publication air concentrations of substances measured in a large exposure survey at sports fields across Europe, which was carried out in August to October 2018, are reported (Schneider et al., 2020a).

Here we estimated exposures of sportspeople from the ELT-derived granules based on the results reported in our previous publications and compared the exposure levels of various user groups with health-based reference values to identify potential health risks from using sports fields with ELT infill material. The assessment covers 17 substances or substance groups identified as the most relevant ones. Various exposure groups were considered, from children aged 1.5 up to adults aged 50. In principal, exposure can occur via inhalation, oral and dermal uptake. During sports activities on the pitches, dermal contact to rubber granules is likely. Inhalation exposure can arise from substances that evaporate from the rubber matrix or are contained in dust particles suspended in the air. Also, swallowing of rubber granules cannot be excluded. For polycyclic aromatic hydrocarbons (PAHs), lifetime extra cancer risks were calculated, following procedures used previously by ECHA (ECHA, 2017, 2018a). This is the first human health assessment for ELT-derived infill material based on such an extensive database obtained from exposure measurements in many European countries.

2. Materials and methods

2.1. Substance selection

Table 1 lists the substances selected for risk characterisation. In addition, cancer risks from PAHs were considered. A much larger set of substances was investigated by ERASSTRI initially (Schneider et al., 2020a; Schneider et al., 2020b). However, only those substances which a) were found in the rubber matrix, b) were shown to volatilise from the matrix in chamber experiments, c) migrated in sufficient quantities to artificial body fluids or d) were considered to have particularly hazardous properties (despite low exposure levels) were included in the risk characterisation.

2.2. Hazard and risk assessment

Toxicological information was obtained by online data searches from authority reports or REACH registration dossiers, by consulting respective websites (https://www.echemportal.org, https://echa.europa.eu/, http://www.inchem.org, https://www.epa.gov/iris) or from toxicological databases (https://www.ncbi.nlm.nih.gov/pubmed/, https://toxnet.nlm.nih.gov/).

Reference values for long-term inhalation, oral, and dermal exposure were adopted from existing evaluations where possible. At exposures below these health-based reference values – according to their definition – no adverse health effects should occur. Values derived by authorities (e.g. ECHA or the European Food Safety Agency, EFSA) or international bodies (e.g. the WHO/FAO Joint Expert Committee on Food Additives, JECFA) were preferred. If no such values could be found, values were determined following the ECHA Guidance document on Information Requirements and Chemical Safety Assessment, R.8 for deriving DNELs (derived no effect levels) (ECHA, 2012). If reliable reference values existed for some routes of interest only, route-to-route extrapolation was considered in case of predominant systemic toxicity according to ECHA Guidance (ECHA, 2012). Long-term reference values were compared to yearly average exposure levels by calculating route-specific risk characterisation ratios (RCRs):

$$RCR = \frac{Exposure\ level}{Reference\ value}$$

RCRs for each route were added up, with RCRs below 1 indicating acceptable exposures.

For PAHs, which are classified as carcinogens, exposure-risk relationships (ERRs) as proposed by ECHA (ECHA, 2018b, 2018a) were used, instead of reference values, to calculate lifetime excess cancer risks. For oral and dermal exposure, the sum of 8 EFSA PAHs (benzo[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, dibenzo[*a*,*h*]anthracene, indeno[*1*,*2*,*3*-*cd*]pyrene, and benzo[*g*,*h*,*i*]perylene) was compared with the appropriate ERR proposed by ECHA (ECHA, 2018a). Note that for dermal exposure limited skin absorption was not considered as a mitigating factor, as results from migration studies with 20% aqueous ethanol were deemed to represent the amount absorbed through skin (Schneider et al., 2020a). As no increased PAH concentrations in air at artificial turfs were found (Schneider et al., 2020a), no extra cancer risk was calculated for inhalation exposure.

Extra risks per year, calculated for individual exposure groups, were added up for lifetime exposure starting at the age of 1.5 up to 50 (see below), assuming regular exposure over 48.5 years. Separate exposure and risk calculations were performed for outfield players and for football goalkeepers.

For cobalt, which is the only other substance in this assessment assumed to be a non-threshold carcinogen, the carcinogenic activity is restricted to the inhalation pathway. As no increased inhalative exposure was measured during the exposure survey, no risk calculation was performed for the inhalative route.

2.3. Exposure assessment

Exposure groups (Table 2) were defined similarly to those in other assessments (ECHA, 2017; RIVM, 2017a; ECHA, 2018a). Sports activities were assumed to start at age 4 and to continue on a regular basis until

Table 1
Reference values (general public) for inhalative, oral, and dermal exposure.

Substance	Reference values			Key references
	Inhalation [μg/m^3]	Oral [μg/kg bw/d]	Dermal [μg/kg bw/d]	
Aluminium	50	140	140	Inhalation: US EPA (2009): occupational LOAEC, 4.6 mg/m^3, neurotoxicity; (ECHA, 2012) oral and dermal: oral rat, reproductive toxicity; EFSA PTWI 1 mg Al/kg bw/week (EFSA, 2008)
Cobalt	Carcinogenic	1.6	1.6	Oral and dermal: chronic, humans, polycythemia; EFSA (2012) 1.6 μg/kg bw/d
Benzothiazole	44	26	26	Inhalation, oral and dermal: subchronic oral rat NOAEL 5.1 mg/kg bw/d (Ginsberg et al., 2011); ECHA (2012)
2-Mercapto-benzothiazole	1090	310	940	Inhalation, oral and dermal: subchronic oral rat NAEL 62.7 mg/kg bw/d, NTP, liver toxicity; DNELs derived for substance evaluation (ECHA, 2014)
Aniline	10.1	5.8	5.8	Inhalation, oral and dermal: chronic oral rat LOAEL 7 mg/kg bw/d, haematotoxicity (CIIT, 1982).; high interspecies factor (Jenkins et al., 1972) (Schneider et al., 2004); (ECHA, 2012)
Cyclohexylamine	260	150	150	Inhalation, oral and dermal: chronic oral rat NOAEL 15 mg/kg bw/d (Greim and MAK Commission, 2003); (ECHA, 2012)
Tert-butylamine	240	100	100	Inhalation, oral and dermal: subacute inhalation rat NOAEC 200 mg/m^3 various effects (ECHA Dissemination, 2018); (ECHA, 2012)
(N-1,3-di-methyl-butyl)-N′-phenyl-p-*p*-phenylene-diamine (6PPD)	45	26	26	Inhalation, oral and dermal: chronic oral rat NOAEL 2.6 mg/kg bw/d, liver, haematotoxicity (ECHA Dissemination, 2018); (ECHA, 2012)
1,3-Diphenyl-guanidine (DPG)	500	75	150	Inhalation, oral and dermal: repeated dose,-reproductive toxicity screening study oral rat NOAEL 15 mg/kg bw/d, body weight (ECHA Dissemination, 2018); (ECHA, 2012)
Methyl isobutyl ketone (MIBK)	2300	5000	5000	Inhalation: chronic inhalation rat BMCL$_{10}$ 57 mg/m^3, nephrotoxic effects (NTP, 2007) (Ad-hoc-AG, 2013); (ECHA, 2012) oral and dermal: subchronic oral rat NOAEL 1000 mg/kg bw/d, US EPA (2003, 2019); (ECHA, 2012)
Cyclohexanone	1200	710	710	Inhalation: subacute rat NOAEC 1000 mg/m^3 (Lee et al., 2018); (ECHA, 2012) oral and dermal: subchronic oral rat NOAEL 143 mg/kg bw/d, systemic toxicity (ECHA ECHA Dissemination, 2018); (ECHA, 2012)
Formaldehyde	100	150	Not derived	Inhalation: Air Quality Guideline WHO (2000, 2010), irritation, 0.1 mg/m^3 oral: chronic oral rat NOAEL 15 mg/kg bw/d, body weight, gastrointestinal effects (Til et al., 1989); (ECHA, 2012)
4-*Tert*-octylphenol	120	110	680	Inhalation, oral and dermal: subchronic oral rat NOAEL 22.5 mg/kg bw/d, various effects (for inhalation consider first-pass effect) (ECHA Dissemination, 2018); (ECHA, 2012)
2-Heptanone	17,000	9830	9830	Inhalation, oral and dermal: subchronic inhalation rat and monkey NOAEC 4787 mg/m^3, no effects (ECHA Dissemination, 2018); (ECHA, 2012)
Bisphenol A (BPA)	36	4	3.3	Inhalation: subchronic inhalation rat NOAEC by Nitschke et al. 10 mg/m^3, body and organ weights (Greim, 1996; NTP, 2008) oral and dermal: t-TDI 4 μg/kg bw/d EFSA CEF Panel (2015) (for dermal consider first-pass effect)
Saturated aliphatic hydrocarbons with a chain length > C9 (SAH > C9)	700	200	2000	Inhalation, oral and dermal: oral TDI for mineral oil saturated hydrocarbon fraction C10-C16 0.2 mg/kg bw/d (BfR, 2011)

age 50. In that period, all sports activities were assumed to take place exclusively on artificial turfs. Specific training of goalkeepers was assumed to start at age 7 and also to continue throughout the active sports life until age 50. Before the age of 4, starting at 1.5 years, small children were assumed to be present on artificial turfs when accompanying older siblings to training sessions or matches. In order to bring the lifetime

Table 2
Definition of exposure groups (EG).

EG no.	Group	Age	Characteristics	Age of re-presentative person
1	Small children as bystanders	1.5–4 years	Toddlers accompanying older siblings	2 years
2	Children	4–11 years	Children playing (training and matches) exclusively on synthetic turfs with ELT-infill	4 years
3	Teenagers	11–18 years	Adolescents performing (more frequent use for training and matches) exclusively on synthetic turfs with ELT-infill	11 years
4	Adults, non- and professionals	18–35 years	Adult sportspeople (professionals or non-professionals) performing exclusively on synthetic turfs with ELT-infill	Adult (70 kg body weight)
5	Veterans	35–50 years	Veterans performing exclusively on synthetic turfs with ELT-infill	Adult (70 kg body weight)
GK 2	Goalkeepers (children)	7–11 years	Goalkeepers (specific training starts at age 7) playing (training and matches) exclusively on synthetic turfs with ELT-infill	7 years
GK 3	Goalkeepers (teenagers)	11–18 years	Adolescent goalkeepers performing (more frequent use for training and matches) exclusively on synthetic turfs with ELT-infill	11 years
GK 4	Goalkeepers (adults)	18–35 years	Adult goalkeepers (intensive use by professionals or non-professionals) performing exclusively on synthetic turfs with ELT-infill	Adult (70 kg body weight)
GK 5	Goalkeepers (veterans)	35–50 years	Veteran goalkeepers performing exclusively on synthetic turfs with ELT-infill	Adult (70 kg body weight)

Table 3
Algorithms for exposure estimation.

Route	Algorithm	Explanations	Units	Values
inhalation	$IE = c_a(x) * \frac{d_d}{24\ hours} * \frac{f_m}{30\ days} * \frac{f_a}{12\ months}$	IE = inhalation exposure	μg/m^3	
		$c_a(x)$ = air concentration of substance x (measured data, 95th percentile	μg/m^3	(Schneider et al., 2020a)
		d_d = duration of daily exposure (default value)	Hours	Table 4
		f_m = frequency of monthly exposure (default value)	Days	Table 4
		f_a = frequency of annual exposure (default value)	Months	Table 4
Dermal 1	$DE = \frac{a_s(x) * FM_{derm}(x) * d_d * \frac{f_m}{30\ days} * \frac{f_a}{12\ months}}{bw}$	DE = dermal exposure	μg/kg bw/d	
		$a_s(x)$ = amount of substance x on the skin (measured data, 95th percentile)	μg/day	(Schneider et al., 2020a)
		$FM_{derm}(x)$ = migration fraction of substance x (measured data, arithmetic mean)	1/h	(Schneider et al., 2020a)
		bw = body weight (default value)	kg	
Dermal 2	$DE = \frac{g_s * 1000 * c_m(x) * FM_{derm}(x) * d_d * \frac{f_m}{30\ days} * \frac{f_a}{12\ months}}{bw}$	g_s = amount of granulate on the skin (default value)	μg/day	Table 4
		$c_m(x)$ = matrix concentration of substance x (measured data, 95th percentile)	μg/mg	(Schneider et al., 2020b)
Dermal 3	$DE = \frac{ca_s * ASA * d_d * \frac{f_m}{30\ days} * \frac{f_a}{12\ months}}{bw}$	ca_s = skin contact area (default value)	cm^2	Table 4
		ASA = amount migrated per surface area (measured data, arithmetic mean)	μg/cm^2/h	(Schneider et al., 2020a)
Oral	$OE = \frac{i * 1000 * c_m(x) * o * \frac{f_m}{30\ days} * \frac{f_a}{12\ months}}{bw}$	OE = oral exposure	μg/kg bw/d	
		i = amount ingested (default value)	g/day	Table 4
		o = oral bioaccessibility	Unitless	(Schneider et al., 2020a)

exposure duration for goalkeepers also up to 48.5 years, exposure from groups 1 and 2 was added for the ages1.5 to 7. No distinction was made between professional and amateur players, who were assumed to practise under the same conditions.

Table 3 explains the algorithms used to calculate exposure. In principle, all pathways can contribute to overall exposure and are therefore considered. As evaporation of volatile substance is expected to be higher under hot climate conditions, air measurements were performed in summer/autumn, and included sites in southern Europe (Schneider et al., 2020a). Both the particulate and gaseous phase were covered by the measurements.

Typically, the 95th percentile of a substance-specific measured value (concentration in rubber matrix, concentration in air or wipes) was combined with measured migration rates (arithmetic means) and/or exposure assumptions (defaults), to obtain a conservative exposure estimate per route for the yearly average exposure.

Three different approaches were used to assess dermal exposure. Method 1 used the results from wipe samples collected from sportspeople after performance, which were multiplied by the migration fraction measured in in vitro studies (Schneider et al., 2020a). Method 2 also used the migration fraction but multiplied it by a default value for the amount of rubber material on skin. Method 3 multiplied the measured migration fraction per granule surface area with a default value for the exposed skin surface.

Table 4 summarises the default exposure parameters for anthropometric data (body weight, skin surface areas) as well as duration and frequency of exposure. Suitable default values fitting to our exposure scenario definitions were selected from recent publications (ECHA, 2017; RIVM, 2017a; ECHA, 2018a). More detailed explanations of the values chosen are provided as Supplementary Material.

3. Results

3.1.1. Reference values

PAHs were assessed using exposure risk-relationships for the oral and dermal routes as proposed by ECHA. A lifetime excess oral cancer risk of

Table 4
Exposure parameters (default values).

EG no.	Exposure group	Exposed skin contact area (cm^2)	Amount of granulate on skin (per event) (g)	Amount ingested (per event) (mg)	Body weight (kg)	Duration of daily exposure (hours)	Exposure days per month (days)	Number of exposure months per year (months)
1	Small Children (1.5–4 years) as bystanders	1035	1	90	12.4	1.5	8	5
2	Children (4–11 years)	1260	1	50	15.7	1.5	16	7
3	Teenagers (11–18 years)	2680	3.3	10	44.8	1.5	20	10
4	Adults, non- and professionals (18–35 years)	3680	6	10	70	4	24	10
5	Veterans (35–50 years)	3680	6	10	70	2	8	10
GK 2	Children (7–11 years)	1290	10	50	24.3	1.5	16	10
GK 3	Teenagers (11–18 years)	2042	10	10	44.8	1.5	20	10
GK 4	Adults, non- and professionals (18–35 years)	2775	10	10	70	4	24	10
GK 5	Veterans (35–50 years)	2775	10	10	70	2	8	10

Table 5
Estimated lifetime cancer risks of sportspeople (outfield players and goalkeepers).

	Lifelong exposure [µg 8 EFSA PAH/kg bw/d]	Excess cancer risk per µg 8 EFSA PAH/kg bw/d	Excess cancer risk
Lifelong exposure: outfield players			
Dermal (method 2)	3.12E-05	4.73E-03	1.47E-07
Oral	3.42E-04	1.43E-03	4.89E-07
Total			6.36E-07
Lifelong exposure: goalkeepers			
Dermal (method 2)	6.05E-05	4.73E-03	2.86E-07
Oral	3.33E-04	1.43E-03	4.76E-07
Total			7.62E-07

1.43×10^{-3} per exposure to 1 µg of the sum of 8 EFSA PAHs/kg bw/d was used. For dermal exposure the lifetime excess cancer risk per exposure to 1 µg sum of 8 EFSA PAHs/kg bw/d was 4.73×10^{-3} (Table 5). No correction for incomplete dermal absorption was made, as it was assumed that the result of the migration experiments constitutes the actual amount absorbed through the skin. As explained above, there was no increased risk due to inhalation as PAH concentrations in the air were not increased at artificial turfs. The same holds true for cobalt.

Sufficient toxicological data were available to determine reference values for all substances (see Table 1 for reference values and sources) except 2-hydroxybenzothiazole. Therefore, a threshold-of-toxicological concern (TTC) approach (Kroes et al., 2004; Barlow, 2005) was applied for this substance. Screening for the genotoxic or carcinogenic potential of 2-hydroxybenzothiazole using different models was performed with the software ToxTree (version 3.1.0 (EC, 2018)). The test methods used were "Structure alert *in vivo* micronucleus test" (Benigni et al., 2009) and "Benigni/Bossa rulebase" (Benigni et al., 2008). No alert for genotoxicity was identified and the substance was assigned to Cramer class III by ToxTree. Hence, according to Barlow (Barlow, 2005) a TTC of 0.09 mg/person/day was used to assess this substance.

3.1.2. Exposure assessment

The detailed exposure results per substance and exposure route as well as the resulting route-specific and combined RCRs are provided as Supplementary Material.

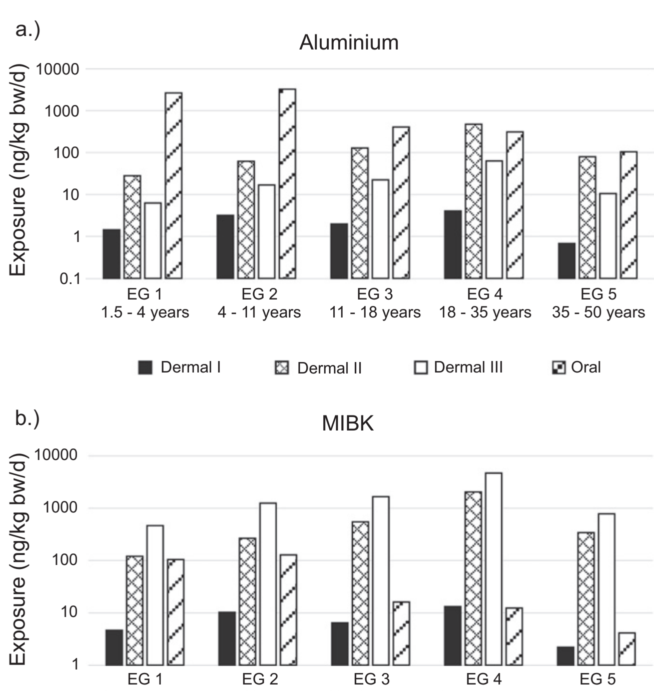

Fig. 1. Oral and dermal exposure estimates for aluminium (a) and MIBK (b)

Concentrations of PAHs, aluminium, and cobalt in the air at sports fields were not found to be different from those in the air at upwind reference points (Schneider et al., 2020a). Therefore, inhalation exposure was not assessed for these substances. Some volatile substances (benzothiazole, *tert*-butylamine, 2-heptanone, cyclohexanone) were found in samples from an indoor facility and the maximum values were used for exposure assessment. For MIBK and SAH > C9 the 95th percentile of all measurements was taken. For substances which could not be detected at sports fields or at reference points, 50% of the limit of quantification (LOQ) was used (Schneider et al., 2020a). Inhalation was found to be an exposure pathway of similar relevance for RCR calculation to dermal exposure (see below), although only a few substances could be actually found in air samples.

Dermal exposure was calculated by three different methods. Method 1, using the dermal loading measured by wipe sampling of sportspeople in the exposure survey (Schneider et al., 2020a), resulted in much lower exposures for all substances than methods 2 and 3. However, only aluminium could be detected above LOQ in these samples and thus concentrations of other substances in wipes were assumed to be 50% of LOQ.

Fig. 1 compares the results for outfield players from the three dermal methods and the oral exposure estimate, using aluminium and MIBK as examples. Similar results were obtained for goalkeepers. The significance of the oral and dermal routes varies according to the substance: oral exposure was the principal route for aluminium, especially in younger children, whereas dermal exposure was the main route in the case of MIBK. Dermal methods 2 and 3 gave similar results, but exposure estimates from both methods were much higher than those from method 1. Although the comparison showed that method 2 was likely overestimating dermal exposure, this method was used for calculating RCRs, as it was considered conservative and could be applied to most substances, whereas method 1 only produced results for some substances.

3.1.3. Risk characterisation

Lifetime extra cancer risks calculated for combined oral and dermal exposure to PAHs are shown in Table 5. Risks from the oral route were highest, but still below 1/1 million for both outfield players and goalkeepers.

As noted above, no reference value based on substance-specific toxicological data could be derived for 2-hydroxybenzothiazole, and, hence, a threshold of toxicological concern (TTC) was applied. These low TTCs, in combination with conservative exposure estimates, resulted in RCRs below 1 for most exposure groups. RCRs slightly above 1 were calculated for exposure groups 4 and GK 4 (1.22 and 1.45, respectively). Notably, 2-hydroxybenzothiazole was not found above LOQ in air, wipe samples or sweat migration fluid. The exposure assessment is based on the assumption that the substance was present at 50% of the respective LOQs in all media. Taking this into consideration, the slight exceedance of 1 in a few RCRs is not a concern (Table 6).

Figs. 2 and 3 show RCRs for all other substances for outfield players and goalkeepers, respectively. There is little difference between the two groups, and exposures (and RCRs) in both groups are highest for

Table 6
2-Hydroxybenzothiazole exposure estimates and RCRs for sportspeople (GK: goalkeepers).

Exposure group #	Inhalation		Dermal (method 2)		Oral		Combined RCRs
	Exposure ($\mu g/m^3$)	RCR	Exposure ($\mu g/kg$ bw/d)	RCR	Exposure ($\mu g/kg$ bw/d)	RCR	
1	2.43E-01	5.40E-02	2.65E-02	2.07E-02	4.33E-02	3.38E-02	1.09E-01
2	6.81E-01	1.51E-01	5.86E-02	4.58E-02	5.32E-02	4.16E-02	2.39E-01
3	1.22E+00	2.70E-01	1.21E-01	9.45E-02	6.66E-03	5.20E-03	3.70E-01
4	3.89E+00	8.64E-01	4.50E-01	3.52E-01	5.11E-03	4.00E-03	1.22E+00
5	6.48E-01	1.44E-01	7.51E-02	5.87E-02	1.70E-03	1.33E-03	2.04E-01
GK 2	9.72E-01	2.16E-01	5.41E-01	4.22E-01	4.91E-02	3.84E-02	6.77E-01
GK 3	1.22E+00	2.70E-01	3.67E-01	2.86E-01	6.66E-03	5.20E-03	5.62E-01
GK 4	3.89E+00	8.64E-01	7.51E-01	5.87E-01	5.11E-03	4.00E-03	1.45E+00
GK 5	6.48E-01	1.44E-01	1.25E-01	9.78E-02	1.70E-03	1.33E-03	2.43E-01

adults, which is due to the assumed longer exposure (exposure on 6 days per week, 4 h per day, see Table 4).

Overall, RCRs are well below 1 for all substances. Highest RCRs were observed for 6PPD, aniline and bisphenol A (BPA). None of these substances was detected in air or wipe samples, and only BPA was found in sweat simulant (aniline was not investigated in the migration study). The higher RCRs for these three substances compared to other substances result from exposure assessments which were mainly based on conservative assumptions in combination with low reference values (Table 1), rather than actually measured exposures.

4. Discussion

Despite several conservative aspects in our assessment (assuming sportspeople practise several times per week continuously from 1.5 to 50 years, application of method 2 for dermal exposure assessment, using 50% of the LOQ when substances could not be detected and assuming high oral granule intake by children and adults), the calculated theoretical extra risk for exposure to PAHs was below 1/1 million. According to ECHA Guidance (ECHA, 2012) as well as to standards in the USA (US EPA, 2000) this is a tolerable level of risk for the general

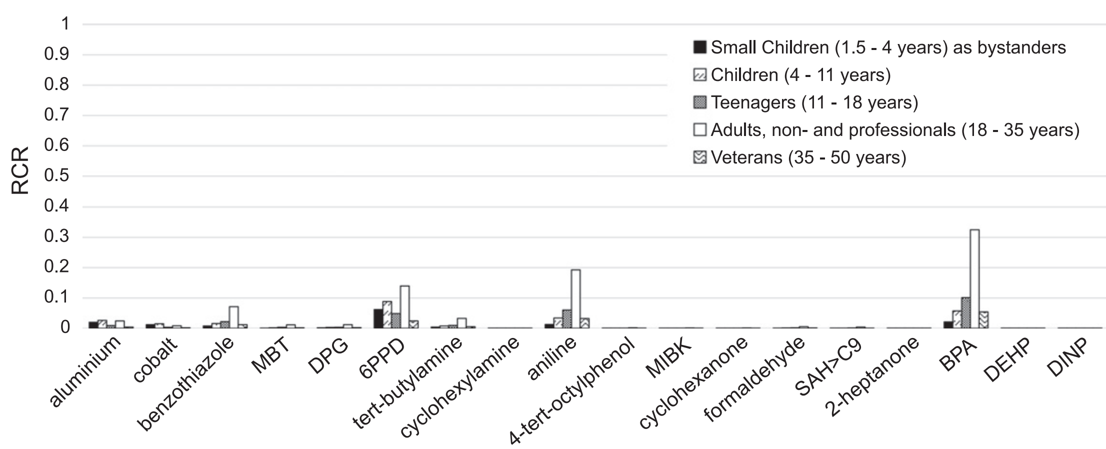

Fig. 2. Combined RCRs for outfield players

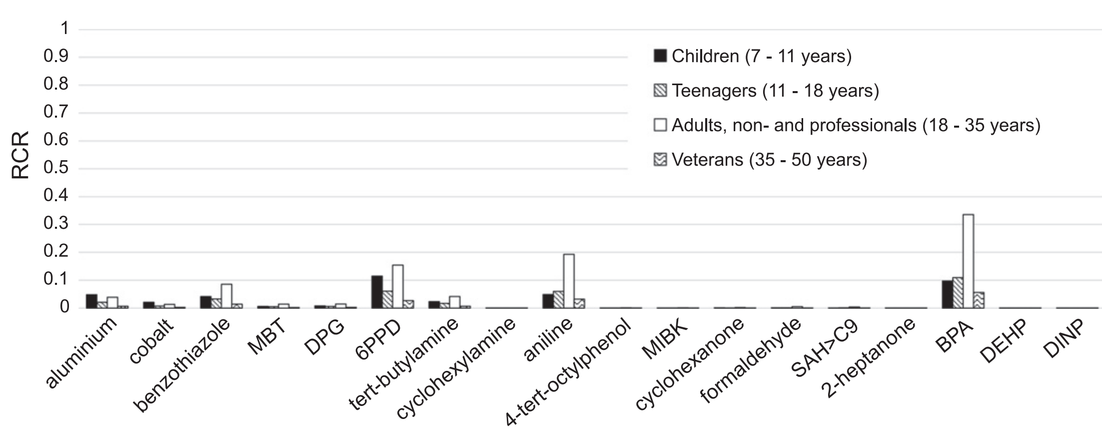

Fig. 3. Combined RCRs for goalkeepers

Table 7
Qualitative uncertainty analysis.

Section	Step	Uncertainty assessment	Tendency	Reasoning
Hazard assessment	Health-based reference values	Low to medium	Conservative	Mostly values derived by authorities, or derived according to ECHA guidance
	TTC approach for 2-hydroxybenzothiazole	High	Very conservative	No toxicological data, Cramer class III
Exposure assessment	Exposure scenarios and exposure groups	Low to medium	Conservative	Continuous exposure over 48.5 years, exclusively on artificial turf with ELT-infill, high frequencies also for non-professionals
	Europe-wide coverage	Low	–	Many countries (mostly those with high number of artificial turfs) monitored
	Monitoring survey: sample numbers	Low	–	17 fields monitored, providing a representative number of samples
	Substance coverage	Low	Non-conservative	Starting from a long list of substances, relevance was scrutinised in various project phases; however, such a list cannot be exhaustive
	Analytical methods and values	Low to medium	Conservative	Accepted analytical methods used; LOQ/2 used when <LOQ
	Coverage of indoor fields	High	Conservative	Only one field; maximum values used
	Default exposure parameters	High	Conservative	Conservative defaults used; not confirmed by measured values
	Exposure calculations	Low	Conservative	95th percentile values for key parameters combined with defaults and measured AMs
	Dermal exposure assessment	High; tendency	Conservative	Method 2 used, although most likely overestimating exposure

population. Also, the RCRs calculated for other substances are well below one and indicate that there is no reason for concern.

Two epidemiological studies investigating the concern over increased incidences of leukaemia and lymphoma among football players in the USA did not find elevated cancer risks for this population group (Washington State Department of Health, 2017; Bleyer and Keegan, 2018). Similarly, our study found the risks from the one group of carcinogenic contaminants present, PAHs, to be below the critical level of concern.

The finding of negligible risks in our study is in agreement with the conclusions of other recent assessments (ECHA, 2017; RIVM, 2017a; Peterson et al., 2018). The Dutch authority RIVM found health risks from playing on synthetic turfs to be "virtually negligible" (RIVM, 2017a; Pronk et al., 2018). According to their conclusions, the release of hazardous substances from rubber granules is very low and does not exceed critical limits for substances such as BPA, phthalates, the metals cadmium and cobalt, and benzothiazoles. In addition, exposure to PAHs was found to be low compared to background exposure from food. Searching the Netherlands Cancer Registry, RIVM also found no increases in cases of lymphoma or leukaemia since the first use of synthetic turfs in the Netherlands.

In 2017 ECHA published the "ANNEX XV report – An Evaluation of the Possible Health Risks of Recycled Rubber Granules Used as Infill in Synthetic Turf Sports Fields" (ECHA, 2017). Substances considered in detail were PAHs, phthalates, formaldehyde, benzothiazole, MBT, MIBK, and benzene. ECHA did not find any reasons for concern but identified several uncertainties and published recommendations to ensure safe handling of synthetic turfs filled with ELT-derived granules. Several of the uncertainties mentioned by ECHA have been addressed by ERASSTRI (improved representativeness of chemical composition data, data gaps regarding unknown substances and their concentrations in rubber granules, and exposure parameters).

With regard to the concentration of PAHs in tyre granulate, ECHA's scientific committees proposed to restrict the concentration of the 8 REACH PAHs to a total of 20 mg/kg to limit carcinogenic risks to a negligible level (ECHA, 2019). As shown previously, PAH concentrations in ELT-derived infill are generally well below this limit (Schneider et al., 2020b). A few assessments published in the past, which evaluated risks from PAHs in rubber granules, applied theoretical exposure assumptions not based on empirical data but presumed high releases of substances from the granules (Pavilonis et al., 2014; Marsili et al., 2015), thus most likely overestimating exposure.

Recently, the US National Toxicology Program completed a 14-day toxicity study with mice. Female mice were exposed to high concentrations of rubber granulate either by gavage, via feed or via their bedding. No signs of toxicity associated with granulate exposure could be detected for any of these application routes (NTP, 2019).

Table 7 summarises the results of a qualitative uncertainty analysis of the major input data of our assessment. Despite the large amount of data accumulated by ERASSTRI there remain several areas of uncertainty. However, due to the many conservative aspects in the approach used, there is a clear overall tendency towards overestimating risk.

Default values for exposure parameters without empirical basis remain an important source of uncertainty. The assumptions for oral uptake used in RIVM's assessment (RIVM, 2017a, 2017b) are based on information in the US EPA Exposure factors handbook (US EPA, 2011). RIVM assumed accidental ingestion of 200 mg granulate per training session or match by children aged up to 11 years. This value represents a 95th percentile for the ingestion of soil, which is in itself of high uncertainty (US EPA, 2017) and cannot easily be transferred to rubber

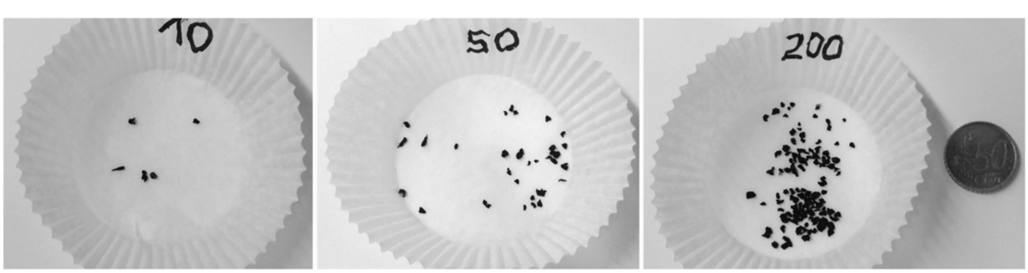

Fig. 4. Visualization of 10, 50 and 200 mg of rubber particles

granules. In 2017, US EPA published an update of the "Exposure Factors Handbook" (US EPA, 2017) and decreased the values for soil ingestion for children aged up to 11 years from 200 to 90 mg.

Individual rubber granules are 0.4 to 2 mm in size and are readily sensed when in the mouth and the natural reaction would be to spit them out. The left and middle photos in Fig. 4 show the amounts assumed to be swallowed daily by adults and children aged 4 to 11 (10 and 50 mg, respectively) in our study, in line with the amounts swallowed as assumed by ECHA (2017). Smaller children are assumed to swallow 90 mg per day, in agreement with ECHA's restriction proposal (ECHA, 2018a). Recently, the California Environmental Protection Agency (OEHHA, 2019) proposed to use 3.6–10.4 g per day for oral exposure. This would amount to an ingestion of between a teaspoon and a tablespoon of rubber granules each day.

5. Conclusion

We present here an assessment of health risks from using ELT-derived infill material based on an extensive database obtained from exposure measurements in many European countries. While some uncertainties remain, ERASSTRI has created a significantly improved database. Evaluation of these data with a conservative approach to risk characterisation, leads us to conclude that there are no relevant health risks associated with the use of synthetic turfs with ELT-derived infill material.

CRediT authorship contribution statement

Klaus Schneider: Conceptualization, Data curation, Methodology, Project administration, Supervision, Validation, Writing - original draft. **Anne Bierwisch:** Data curation, Formal analysis, Investigation, Writing - review & editing. **Eva Kaiser:** Data curation, Formal analysis, Methodology, Investigation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.137721.

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Town of Arlington, Massachusetts

Notice of Intent: 40-42 Forest Street

Summary:
Notice of Intent: 40-42 Forest Street
Documents: 40-42 Forest Street Notice of Intent Application Package

This public hearing will consider a Notice of Intent for work at 40-42 Forest Street. Proposed activities include partial demolition of the existing two-family house and the removal of various site features within the Riverfront Area to Mill Brook, as well as Buffer Zone, Adjacent Upland Resource Area, and Land Subject to Flooding (Zone AE).